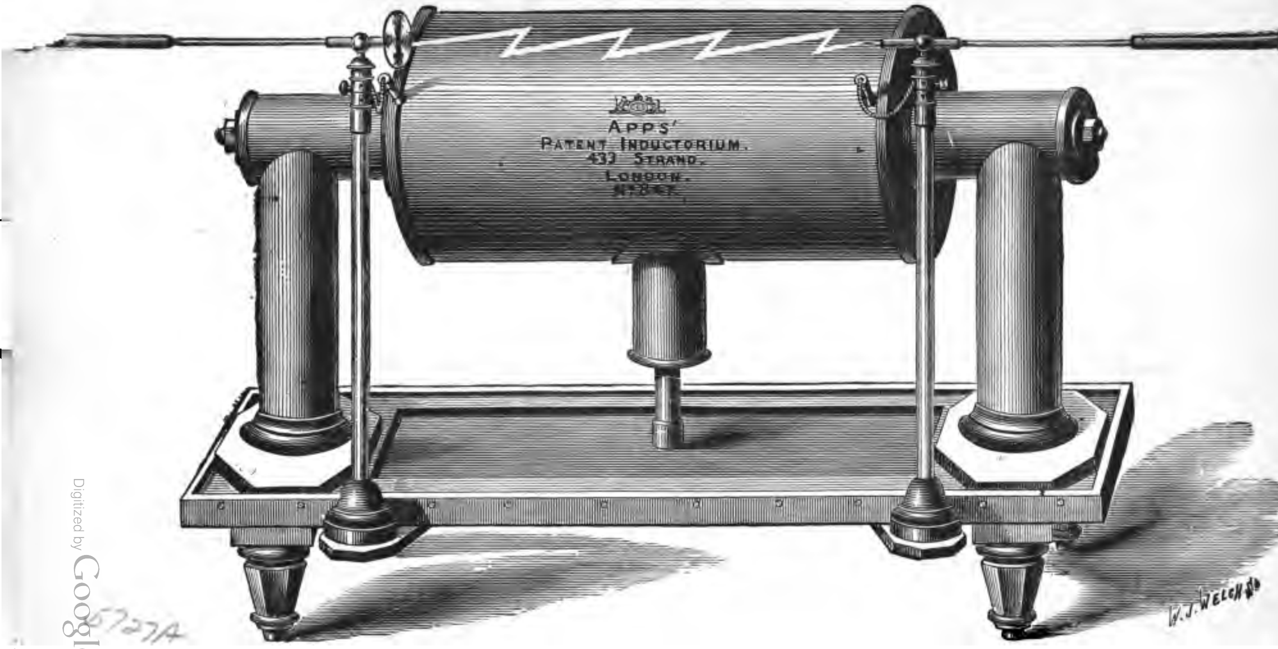
INDUCTION COILS.



[*Frontispiece.*

INDUCTION COILS.

A Practical Manual

FOR AMATEUR COIL-MAKERS.

BY

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AUTHOR OF "THE ELECTRO-PLATERS' HANDBOOK."

WITH MORE THAN 100 *ILLUSTRATIONS.*

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PREFACE.

This book has been written to meet the wants of amateur electricians desiring a practical acquaintance with induction coils, their accessories, and suitable batteries for working such coils. Hitherto, all information obtainable on this subject has been scattered in a fragmentary manner through a number of text books on the science of electricity, and throughout the volumes of the *English Mechanic*, *Design and Work*, *Work*, and similar journals, which cater and have catered for the wants of amateur scientists. Information obtained from such sources as these must of necessity entail the expenditure of much time, money, and labour. It has been the aim of the author to reduce this expenditure, by placing in the hands of the amateur coil-maker a cheap and handy volume giving a general insight into the construction of ordinary spark coils, medical coils, and batteries for working them.

The author's thanks are due to Mr. K. Schall, Messrs. King, Mendham & Co., T. Gent & Co., Woodhouse & Rawson United, Limited ; Cathcart, Peto & Radford, and the Electric Stores Company, who have kindly lent blocks for many of the illustrations. The frontispiece, showing "The unrivalled Induction Coil, by Mr. Alfred Apps," and the illustrations of his coils and contact-breaker, have been kindly lent to the author and publisher by Mr. Apps for exclusive use in this book.

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INDUCTION COILS.

CHAPTER I.

INDUCTIVE THEORIES AND EXPERIMENTS.

§ 1. Definition of Induction.—What is induction? What are Induction Coils? By common consent this term is employed as a name for an apparatus (invented by Mr. Mason, and subsequently improved by M. Ruhmkorff), consisting of a bobbin wound with a short coil of stout wire, over which is wound a secondary coil of very fine wire of many thousand turns, well insulated from each other, the whole fitted with a central core of iron. The name is not happily chosen. It should have been inductive coils, since the word "inductive" means "leading, persuasive, producing," and the use of these coils is to produce a high tension electric current from one having a low tension. The term Inducing Coils would have been still more

correct, since inducing is part of the verb induce, a word meaning "to influence; to persuade; to actuate; to impel; to allure." The appropriateness of these terms to the electrical instruments under consideration will be seen as we proceed in explaining the principles of their construction, and their mode of action. The word "induction," on the other hand, comes from the verb "induct," which means "to introduce; to bring in; to put in possession;" none of which apply appropriately to the action of the inducing or inductive coil. Some writers on the subject exalt the term to its Latin form of inductorium. As, however, the terms "induction" as applied to induced electricity, and "induction coils," as a name for the instrument under consideration, are now well established, I shall continue using them until more correct terms have been agreed upon by competent authorities. Mr. John T. Sprague defines induction as "the name given to effects produced outside of the body exerting a force, or out of a circuit to which the force is directly applied."* This is not a very clear definition. The wonderful influence exerted by a current of electricity on all material lying in and near to its path, is not clearly defined by this authority. Perhaps it will be more clearly understood if put to the reader in the following words. Induction is the name given to the attracting or repelling influence exerted by a current of electricity on all material lying in and near

* "Dictionary of Terms in Electricity: its Theory, Sources, and Applications." By John T. Sprague.

to its path.* This will be shown further on as we explain its theory.

§ 2. THEORY OF INDUCTION.—Early theories respecting induction were based on the assumption that there existed two electricities, one positive and the other negative, both of which were fluids. The fluid theory has been abandoned by electricians, because modern observation of electrical effects has rendered the theory no longer tenable. The other theory of two electricities, that is, two kinds of the same thing, such as positive and negative, answering to the terms male and female, is also fast passing away. We still speak and write of electricity as being positive and negative, but we use these terms more to distinguish the backward or forward movements of the current, than to imply the existence of two separate and different forms of energy. Some of the newest theories respecting induced currents of electricity are based on the assumption that all bodies are enveloped in a fluid, to which the name of ether has been given. The electric current, in passing through a conductor, disturbs the arrangement of its component parts, and these in turn are said to disturb the ether, which then transmits the disturbance to contiguous bodies. Whether this theory is based on fact or on fancy we cannot here determine, but the fact remains that there is such a disturbance set up in bodies near to electric conductors, and these are especially observable at the instant when the

* It has been likened by Ampère and Professor Thompson to a magnetic shell enclosing the conductor of an electric current.

current of electricity is interrupted, as when the electric circuit is broken. The observed effects go to show that the interruption causes a kind of eddy or back-lash in the current, which is felt by other bodies susceptible to its influence, and observed in them as a current flowing in an opposite direction to that of the inducing current. The inducing effects are more strongly shown in conductors actually in contact with the inducing conductor through a thin, but perfectly insulating substance; but they are also observed in conductors separated by air space only from the inducing conductor. This goes to show that either the air or some similar invisible conducting medium transmits the inducing effects of one conductor to another conductor.

§ 3. PRINCIPLES OF INDUCTION.—Before we proceed further in the study of induction or of inductivity, it will be advisable to notice a few of the principles, facts, or laws, governing its action. These, when well understood, will guide us in the construction of the coils hereafter described.

The inducing conductor and the conductor to be induced must run parallel, side by side. The inductive effect is weakened when they cross each other, and may be neutralised by a transverse position. The bare conductors must not touch each other, but must be separated by an insulating medium, or so-called non-conductor of electricity. A list of these and their relative values is given in section 80, p. 221. If two conductors are in contact at any part of the circuit, or are insufficiently insulated, they combine in forming one

conductor conveying the primary current in one direction only, and, consequently, there will be little or no inductive effects observed. The insulating medium should be as thin, and yet as perfect as can be obtained. The turns of the conducting wires of a coil should not only be wound regularly side by side to get the best effect, but should also lie close to each other, separated only by the thin insulating medium, since each turn exerts an inductive influence on its neighbour, and this influence is weakened by over insulation and want of contiguity. It will be seen further on, when we consider the relative values of insulating mediums, that the best of these are conductors of electricity when the tension or pressure of the current is sufficiently high to overcome their resistance. Therefore, in planning the insulation of the wires, and other parts of a coil, regard must be had to the tension of the current employed in working it, for if we employ a current of higher tension on an imperfectly insulated or badly arranged coil, with a view to obtaining better effects from it, the extra current forced through the coil will overcome the resistance of the insulation and break it down. Wherever this occurs in a coil, the inductive effect ceases, because all the imperfectly insulated turns of wire unite to form one large conductor in which the inductive effects of the well insulated turns are absorbed.

The inductive effects of a current are observed by at least three manifestations. 1. When the insulated conductor is wound as a wire around a mass of soft non-magnetic iron, the current of electricity passing through

this conductor induces magnetism in the iron, and converts it into a magnet whilst the current is passing. The effect here manifested as magnetism only exists whilst current is passing through the conductor, and ceases when the current is broken. 2. When the insulated conductor is doubled on itself, or wound into a spiral, or made into a coil with or without a core of soft iron, the inductive effect of one turn of wire on another is manifested at the terminals of the battery or other generator of electricity (*when the circuit is broken*) by a bright spark, which increases in brightness with the number of turns made by the wire. A similar spark is observable at the terminals of a wire wound or laid parallel to the conductor in the main circuit, when the necessary conditions are present. This effect is only observed at the instant of breaking contact with the battery, or, in other words, on the instant of the rupture of the main circuit wire. 3. When a wire is thus made into a long spiral with several coils close to each other, and the bared metal parts near the battery terminals are held in the naked and moist hands of a person, that person will experience a tingling sensation in the nerves of the fingers at the instant when the circuit is broken, and also when contact is made again with the battery. This manifestation of induction is also only momentary, but can be repeated as often as contact is made or broken. When a long coil of fine wire is wound on and over the main coil, the tingling sensation can be felt at the terminals of the second coil when contact is made or broken at the terminals of the first coil.

There are, therefore, three distinct manifestations of electric current induction, or the inductive effects of the electric current observable, viz., the magnetic, the calorific, and the physiological. We will consider each, and prove them by means of experiments before we proceed further.

§ 4. MAGNETIC EFFECTS OF INDUCTION.—The discovery of these effects was made by Hans Christian Oersted, a Danish philosopher, who was doctor of philosophy to the University of Copenhagen, in the year 1800. Whilst occupying this position, he demonstrated the identity of the forces of magnetism, electricity, and galvanism. In a treatise published on the subject, he proved that "there is always a magnetic circulation round the electric conductor, and the electric current, in accordance with a certain law, always exercises determined and similar impressions on the direction of the magnetic needle, even when it does not pass through, but near the needle." He found that a magnetic needle was influenced so much by the current of electricity passing through a conducting wire as to deviate from its usual position when brought near the wire, and place itself in a position transverse to the path of the current. When this great discovery was published, it received close attention from French *savants*, and experiments were made which led to the discovery that a current of electricity passing through a wire not only influenced a magnetic needle brought near to the wire, but also exerted an inductive influence on another wire laid parallel to it. Following these researches, Professor

Faraday made another discovery.* He found that when a coil of insulated copper wire was wound around a bundle of steel needles and a current of electricity was sent through the coil, the needles became magnetised, and, after breaking contact with the battery several times, the steel needles became permanent magnets. When soft iron wires were substituted for the steel needles, the magnetic effects were temporary, existing only whilst the current was passing through the coil. This part of Faraday's discovery receives an important application in the construction of induction coils, since their efficiency is to a great extent determined by the magnetic efficiency of the iron employed in their cores. To prove this, we will have recourse to two or three simple experiments.

1. Procure a short bar of soft iron, 3½ inches in length by ⅜ inch in diameter. This must be of the best soft charcoal iron, well annealed by heating to redness in a fire and allowed to gradually cool with the hot ashes through a period of twelve hours. Wind on this a long spiral or helix of No. 20 silk or cotton-covered copper wire, with the folds wound regularly side by side. The iron will be found to be non-magnetic, that is, it will not attract bits of iron wire and iron filings. Connect the two ends of the coil to a battery of three or four cells in series, and hold the iron core to the iron filings. The filings will be attracted to the iron core, as to a

* Professor S. P. Thompson attributes this discovery to Arago and Davy, in the year 1820. "Elementary Lessons in Electricity and Magnetism," p. 286.

permanent magnet, thus showing that the current of electricity circulating in the coil of wire wound on the iron core has exerted an inductive effect on the iron and converted it into a magnet. Disconnect one end of the wire coil from the battery, the filings will at once fall from the iron, thus showing that the iron has lost its power of attraction at the instant when the current of electricity ceased passing through the coil of wire wound over the iron. Measured in fractions of time, this magnetic effect is not absolutely instantaneous, since all iron manifests a slight reluctance to receive and also to give up magnetic effects, because it takes time to fully magnetise a piece of iron and also to demagnetise it—that is to draw out the charge of magnetism. But, in the case of very soft iron, the time occupied in doing this is so small as to merit the term instantaneous.

2. Get a piece of hard-hammered iron of similar size, and wound in a similar manner, and repeat the experiment. The hard iron is not so readily magnetised, nor does it part with the magnetic charge so readily as the bar of soft iron. The iron filings and bits of iron wire will be seen to stick to the bar after the current of electricity has been interrupted. This experiment proves the unsuitability of hard iron to form the core of a coil or the core of an electro-magnet, since its reluctance to receive and part with magnetic influences will hinder the efficient working of the cores. If hard iron is used in an electro-magnet, its magnetism will be retained after the electric circuit is broken, and, as a consequence,

the armature of the magnet will not be released. If hard iron is used in the core of an induction coil, it does not receive a sufficient charge of magnetism, since hard iron is not so readily magnetised as soft iron, and it does not part with its small charge when the electric circuit is broken. From both causes, and for both reasons, therefore, the inductive impulses are lessened in frequency and intensity.

3. Substitute a bar of hard steel in place of the bar of iron, connect one end of the wire helix to a coarse file and the other end to the battery. If the steel has been recently hardened, it will, probably, be non-magnetic, and will not attract nor hold iron filings. Now draw the end of the opposite battery wire over the teeth of the coarse file, and thus send a current of electricity through the wire helix in a series of jerky impulses. Each such impulse will exert an inductive effect on the molecules of hard steel held in the helix, and gradually induce them to assume a magnetic polarity. The effect of this action will be to convert the steel bar into a permanent magnet, which will not part with the magnetism when the inducing current of electricity has ceased to pass through the helix. If a strong battery of three or four cells has been employed in this experiment a bright spark will mark each interruption of the current whilst drawing the battery wire over the teeth of the file, and this spark will become brighter as the steel becomes magnetised, because its magnetic condition will exert an inductive influence on the coils of the wire helix surrounding the bar, and these will also have an inductive

effect on each other. When the steel has been magnetised a further experiment illustrating its inductive influence may be performed. Connect the ends of the wire helix to the terminals of a delicate galvanometer, such as the horizontal galvanometer shown at Fig. 58, p. 113, loosen the helix and withdraw the magnetised steel. At the instant of withdrawing the steel, a current of electricity will be induced in the coils of the helix, causing a deflection of the galvanometer needle, and, on thrusting the steel again into the helix, another impulsive current will be sent through the coil in another direction. This property has been made use of in the construction of magneto-dynamo machines, and in dynamo electric machines. When the hard steel core has been fully magnetised, there will be little or no magnetic changes in its condition under successive impulses of the current, and it will cease to give back the inductive impulses communicated by the interrupter. Because of this reluctance to receive and give up magnetism, it is unsuitable as a core for an inductive coil.

As an illustration of the correlation of energy, it may be mentioned here that similar inductive effects have been observed in the near neighbourhood of pipes conveying high pressure steam, and an Italian named Donati Tomasi, in or about the year 1875, performed some experiments with a helix of steam pipe, in which he claimed to have succeeded in magnetising an iron core by means of high pressure steam driven through the coils of pipe.

§ 5. CALORIFIC EFFECTS OF INDUCTION.—Whilst

performing the experiments mentioned in § 4, we shall have seen some of the calorific effects of induction, but it will be advisable to repeat those experiments with a view to obtaining these effects only. By calorific effects, I mean those which appear to the eye as fiery sparks, and results only obtainable by heat under other conditions, the word calorific being taken in its general sense as meaning " heating, or making hot." If we take a battery of some three or four cells in series, connect a long wire of copper to one of the terminals at one end of the battery, and touch the terminal at the other end with the end of the wire, we shall observe a bluish spark, which will be red and fiery if we draw the end of the wire along the milled edges of the terminal binding screw. Bend the wire in a zig-zag manner with the folds nearly touching each other, then note the difference in the brightness of the spark. Next, wind the wire around a pencil or a ruler, with the coils close to, but not touching each other, and repeat the experiment. The spark will be longer and brighter, because each coil will have an inductive effect on its neighbour, and thus increase the tension or stress of the current. Now replace the pencil with a rod of iron, and again repeat the experiment. There will be a perceptible increase in the length and brightness of the spark, due to the added inductive effect of the magnetised iron on the coils of wire. This effect may be thus explained: The battery power is absorbed by the iron and its surrounding coils of wire on closing the circuit of the battery, when they receive a charge of electric energy; this is given up on

breaking the circuit, and the discharge of this extra current is shown in the form of a bright spark. The interest attending these experiments is increased by again using the file employed in the experiments mentioned in § 4. The sparks given off from the file may be directed against the naked hand without experiencing any heat or painful sensation from their contact with the hand, but their calorific character can be easily demonstrated by holding a bit of cotton wool coated with finely-powdered gunpowder or lycopodium in their path, or rolling a few bits of gun-cotton around the end of the wire.

These sparks are caused by the combustion of small particles of the conductor. They are more bright from a file than from a piece of brass, because the current frets off small particles of carbon from the file, and these burn with more brilliance than particles of brass. We shall note that the calorific effects of induction are only observed on disruption of the circuit, and then only at the points of disruption or contact. Hitherto, the experiments have only illustrated the action of the current in the primary coil, and the inductive effects of the current on its coils and enclosed core of iron. The same kind of action goes on in the primary coil and core of an induction coil, and the effects are produced by frequently interrupting the flow of the current, as by drawing the wire over the teeth of a coarse file. We must have a means for interrupting the flow of current, and the act of interrupting this will cause the points of contact to burn away. Hence it is necessary to have

these points made of a material that will not be readily consumed by the sparks. This will be more particularly noticed further on, when we treat of the mechanical means to be adopted to provide an automatic interrupter of the current. The calorific effects of induction will also be seen when we examine more closely the action of the spark induction coil.

§ 6. PHYSIOLOGICAL EFFECTS OF INDUCTIVE ELECTRICITY.—The use of this term covers all the observed effects of electricity on animal tissues, but is here specially considered in its relation to the inductive effects of the electric current. These effects were probably the first ever observed as evidences of current electricity, since they led Galvani to the discovery of a battery (for generating an electric current) which now bears his name, and is called a galvanic battery. All students of electrical science are more or less acquainted with one or more versions of the discovery by this famous Italian physiologist whilst experimenting on frogs' legs. Whilst searching for evidences of animal magnetism and electricity, he accidentally discovered that a current of electricity passing through the leg of a frog caused contraction of the muscles and a life-like movement of the tendons. Like many other men who approach a subject with predetermined, fixed ideas, he attributed those movements to electric currents generated in the frog's legs; but subsequent researches by Volta and others have proved beyond doubt that animal tissues are affected by the passage of an electric current through them, and the muscular contractions of the frog's legs observed by

Galvani were caused by an electric current generated between two dissimilar metals in contact with each other, and in contact with the frog's legs. Since those famous men have passed away, the subject has been closely investigated by scientists, and a great advance has been made in our knowledge of the physiological effects of electric currents; but much remains to be done before this can be said to be exalted to the rank of an exact science.

Animal tissues are not good conductors of electricity. In 1883 Dr. W. H. Stone published an account of some experiments made to determine the resistance of the human body to the passage of an electric current. As a result of those experiments he found that the average resistance of a living man from foot to foot was from 930 to 945 ohms, whilst from foot to hand the resistance was from 1,027 to 1,320 ohms. In a dead man, he found the resistance from foot to foot to be 1,150 ohms. Professor Elihu Thompson has stated in evidence at an inquiry into the cause of death from an accident to a man coming into contact with electric light wires, that "the average resistance of the body equals 3,000 to 4,000 ohms." Mr. S. R. Bottone, who has studied and practised the application of electricity to the cure of disease, states in a letter to me that "the *dry hand* has an average resistance of 5,000 ohms to the square inch of surface; but when moistened, the resistance is much less." Mr. K. Schall states that the resistance of the human body varies from 700 to 4,000 ohms, and may be from 50 to 10,000 ohms, according to the size of

electrodes employed, &c., &c. It will thus be seen, even taking the lowest estimate of resistance, that, unless urged at a very high pressure, only a fractional part of an electric current can be sent through the human body. It needs, however, only a small quantity of current to demonstrate physiological effects in living animal tissues; how small has not yet been determined, or is not well known.

Sensible effects—that is, effects which can be immediately felt by the sensation of pain or discomfort—vary considerably in human beings. If, whilst performing the experiments mentioned in the two preceding sections, the performer will grasp the naked wire (which he uses to make contact with the file) in such a manner as to have a part of it touching the forefinger whilst contact is made with this finger and the wire together, a tingling sensation will be experienced in the finger every time contact is broken. This sensation will be caused by the discharge of the extra induced currents through the finger, and the intensity of this sensation will increase with the number of cells added in series to the battery. If a large battery of strong cells is employed, the induced charge may be felt in both hands whilst resting one on the file and making contact with the other. With a large battery of 30 or more chromic acid cells, a sufficient volume of current can be sent through the body direct, without the assistance of any coil, to cause a tingling sensation at the points of contact. In some sensitive persons, and also when the skin is moist, the current from such a battery will cause a painful sensa-

tion which cannot be borne. Dr. Stone found that when the hands and feet were well soaked in brine, and the contact points of lead or zinc were made very large (say from 50 to 100 square inches of surface), even the current from three cells was complained of, whilst in other cases the current from 10 cells was hardly felt. In some experiments performed by Dr. Tomkins and Mr. Bottone, they found that a 32-volt current was distinctly felt when a square inch electrode was held in one hand and the other placed on the nape of the neck. The current thus sent through this part of the body was measured, and found to be 32 milliampères, or, in other words, $\frac{32}{1000}$ of an ampère. This shows that a very small current of electricity may be felt by human beings in the form of a tingling or stinging sensation.

When a properly-made induction coil is in action, the sensation experienced by touching the two terminals of the secondary coil with any two parts of the body at the same time, is that of a painful throb or shock, hence those coils are sometimes named shocking coils. It is not safe to take shocks from large-spark induction coils at any time, and it is dangerous for some persons to take a shock from even a small coil.

It is not in my province to open up a discussion in these pages on the application of physiological effects of inductive electricity to the relief and cure of disease. The subject is a most interesting one, but it demands careful treatment by an experienced, conscientious practitioner, since much harm may be done by a wrongful application of this potent remedial and curative agent.

CHAPTER II.

HOW TO CONSTRUCT INTENSITY OR SPARK COILS.

§ 7. THE PARTS OF INTENSITY COILS.—Induction coils, to give sparks at the terminals of their secondary wires, and also those coils which are made for medical purposes and named "medical coils," are constructed of the following parts: 1. The stand, or base, or pedestal of the coil bearing the coil itself and all its accessories except the battery. 2. The bobbin, or reel of the coil, on which the wire is wound. 3. The iron core forming the body of the bobbin. 4. The primary wire forming the primary coil, through which the primary current passes. 5. The secondary coil of wire wound on the outside of the primary wire, or coil, in which the secondary current is induced. 6. The automatic break, or interrupter, a mechanical arrangement for interrupting the current passing through the primary coil. 7. Terminal brass screws or pillars for the ends of the primary and secondary wires. To these may be added, for spark coils alone, a compact mass of tinfoil sheets named "a condenser," to absorb

and condense the extra current induced in the primary coil; and a regulator or commutator to regulate or change the tension and direction of the currents in a medical coil. These parts will now be separately mentioned and described.

§ 8. THE BASE, STAND, OR PEDESTAL OF A COIL.— This must be of wood, ebonite, vulcanite, or similar non-conducting substance. It may be made of glass or of polished marble or slate. Metal will be altogether unsuitable, because it will absorb into itself part of the inductive effects of the current. Wood is generally used. The most suitable woods are walnut, teak, mahogany, or oak, or any other close-grained and tough wood capable of receiving a high polish when finished. The darker woods look best when nicely polished. The shape of the base, and also its size, must be determined by the size and shape of the coil to be placed on it, and also any other appliances it may have to bear in addition to the coil. For ordinary spark induction

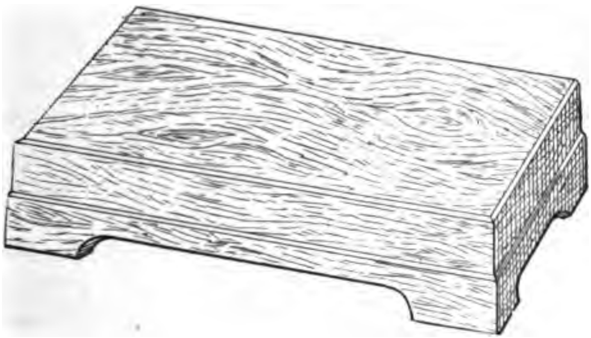


FIG. 1.—Base of Induction Coil.

coils the shape in general use is rectangular, that is, shaped as shown at Fig. 1. The same form is used as a base for small medical coils. The base should be fully 1½ inches wider than the diameter of the coil, if this is 4 inches or over, and double the length of the coil to provide room at each end for the automatic interrupter and the terminal pillars. It should either stand on four turned ornamental knobs at the corners, or be made in the form of a hollow base. The latter

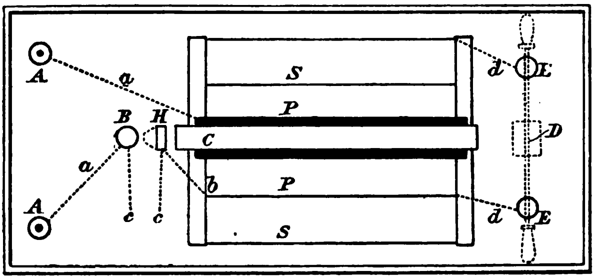


FIG. 2.—Plan of small Spark Coil.

A. A.—Battery Terminals. *B.*—Break Pillar. *C.*—Core of Coil. *D.*—Dischargers. *E.E.*—Discharger Pillars. *H.*—Break Hammer. *a.a.*—Course of Primary Wire Ends. *b.*—Course of Primary Wire to Break. *c.c.*—Course of Wires connecting the Condenser to contact Breaker. *d.d.*—Course of Secondary Wire Ends. *P.P.*—Primary Wire. *S.S.*—Secondary Wire.

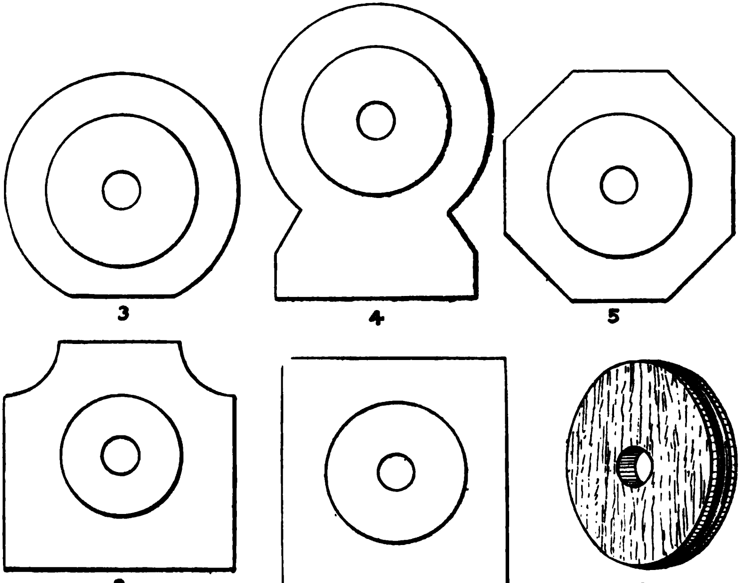
is preferred, because then all wire connections can be brought down through the base into the hollow part, where they are hidden from sight when the bottom board is put on and fastened with long thin brass screws. Such a base, showing the connections beneath, is shown at Fig. 2. If the base is intended for a spark coil, it should be made in the form of a shallow box, and the hollow beneath the coil be occupied by the

condenser. Medical coils are also mounted on boxes fitted with drawers, containing the electrodes and other accessories. In some forms of the medical coil, a box beneath the coil contains the battery to work it, and the coil is mounted on the lid of this box. In other forms, the coil is contained in one compartment of a box whilst the battery is placed in another part of the box. Street shocking coils are fixed on a broad table furnished with dial, electric bells, commutator, switches, studs, and brass handles. Some makers affect the vertical style of induction coil, fixing the coil on its back end vertically on a pedestal of wood, which may be round, octagonal, or square to suit the fancy.

The base should be nicely planed, smoothed and polished before the coil and its accessories are mounted on it.

§ 9. THE REEL OR BOBBIN OF THE COIL.—The ends of this may be of wood, ebonite, vulcanite, or any similar substance. It may be made of glass, polished marble, or slate. It must not be of metal, as this will absorb the inductive effects of the coil. The ends are usually made of the same kind of wood as the base of the coil. They may be round, square, octagonal, or shaped as shown at Figs. 3 to 8, as fancy may determine. Their form will in no way affect the working of the coil. The diameter of the reel ends must be determined by the size of the coil. Some dimensions for these are given in the table of coils in § 21. The dimensions of a bobbin for a coil must be determined by its intended use and the quantity of wire to be

wound on the bobbin. Having first decided on the length or the weight of wire to form the coil, and selected the gauge, find from the table given on p. 218 the number of turns to the inch taken up by the selected gauge. From this may be calculated the space likely to



3 4 5

6 7 8

FIGS. 3—7.—Various forms of bobbin ends for coils.
FIG. 8.—Round bobbin end with grooves turned on the edge.

be occupied by the wire. To this must be added the space likely to be taken up by the sheets of insulating paper. It is advisable to have the bobbin ends from 1 to 2 inches larger than required to hold the wire of a spark coil, and to fill up the vacant space with cotton

after the coil is wound. Sparking from the secondary terminals to adjacent turns of wire is thus prevented. The thickness of the wood should not be less than $\frac{3}{8}$ inch, and it need not exceed $\frac{5}{8}$ inch for all ordinary-sized coils. Ebonite is superior to wood in that it is a better insulator than wood. As the wire coils touch the bobbin ends, and there is a possibility of leakage across the coils of wire through the ends, it will be advisable to well dry or bake the wood before cutting out the ends, and then soak them in hot melted paraffin until bubbles cease to be given off from the wood. The ends should then be wiped free from surplus paraffin whilst warm, then set aside to cool and harden. The body of the bobbin should be next prepared. In small spark coils, this may be the core of the coil itself. The prepared bundle of iron wires to form the core is first wound with a few turns of strong paper dipped in thin glue and made quite smooth, then holes are made in the bobbin ends to exactly fit the paper-covered core, and the ends are firmly glued on the core, which thus forms the body of the bobbin. When this is done well, that is the core ends fitted closely before being glued on, a very good coil bobbin for small coils may be made by this method.

The following is a better method for both small and medium-sized coils. After having decided upon the size of the core, get a smooth ruler, or piece of round smooth wood, or a glass rod the length and diameter of the core. Around this, roll one turn of thin strong paper well coated with soap. Over this, roll some

strong paper, such as cartridge paper, well soaked in thin glue, until a tube $\frac{1}{16}$ inch in thickness has been formed, then set aside to dry and harden. The wood discs for the bobbin ends must now have holes turned in their centres to exactly fit the ends of the paper tube just formed. These holes may be cut with a centre bit, if the discs are for small coils. They should not be cut clean through of the same size, but a narrow and thin shoulder should be left near the outer edge of each, and against this the edges of the tube will rest when the ends are fitted on the tube. A thin ring should be cut off the ends of the tube with a sharp knife to ensure the edges of the tube fitting true with the shoulders in the bobbin ends. The ends may then be fitted on the tube, set quite true and parallel to each other, and secured there with some freshly prepared good hot glue, leaving the wooden former in the tube until the glue is set. When the glue has set and the tube is hard enough, the whole should be well soaked in hot melted paraffin, to ensure perfect insulation.

A well-made tube of paper, well soaked in paraffin wax, is the best material yet discovered for the bobbin bodies of small induction coils. Wood has been employed, but this is liable to split and warp whilst being heated. Gutta-percha has been employed and may be said to have had its day, as it becomes brittle with age, then cracks and becomes useless as an insulator. Gutta-percha is said to be very liable to disintegration, and to be easily pierced by internal sparks when employed in spark coils. The primary

wire of a small coil should not be separated from the core by a greater thickness of material than is needed to make a sufficiently strong bobbin body for the coil, and this body should be a good insulator. The thickness of the tube sides must be adapted to the size of the coil. In very small coils to give from $\frac{1}{8}$ inch to $\frac{1}{4}$ inch spark, the sides need only be $\frac{1}{16}$ inch in thickness. This should be increased to $\frac{1}{8}$ inch for 1 to 3 inch coils, and a further increase up to $\frac{1}{4}$ inch is advisable for larger coils. Special attention to the thickness of tube is advisable in very large spark coils, since there is a liability on the part of the secondary coil to send sparks from its end turns right through the tube to the primary, if the tube is in any way imperfect. Some makers make the tube thicker at the ends, to guard against this danger.

If thin sheet ebonite is employed in making the body of the bobbin, it may be worked in the following manner. Take the measure of the core in the form of a short ruler of smoothly polished wood. Cut a piece of thin sheet ebonite just wide enough to go around the ruler, warm this before a fire until soft enough to bend smoothly around the ruler, then hold it firmly and secure the joint with melted shellac. Now cut another piece of sheet ebonite just wide enough to go around the first, treat it as the first was treated, then close the joint with melted shellac on the opposite side to the first joint. In this way any thickness of tube may be built.*

* Ebonite bobbins with ends made to screw on the bodies, and loose discs of ebonite for the divisions, are made by professional workers in this material, for large spark coils.

If the bobbin is to be used in constructing a medical coil, the body should be formed on the regulating tube of brass instead of on a wooden ruler, one thickness of soaped paper being rolled on the brass tube before forming the body on it, as the tube should slip freely through the body without having too much play, or a wider air-space than necessary between the primary and core of the coil.

§ 10. THE CORE OF THE COIL.—The experiments detailed in §§ 4 and 5 will have prepared us to use a core of soft iron in constructing a coil. We may obtain inductive effects without a core, but these effects will be much increased and intensified by the use of an iron core. The core may be of solid soft iron, but this will be inferior to one made of soft iron wires bound in a bundle, because solid iron will manifest a reluctance to receive and to give up a magnetic charge. The best material for the core of a coil, is soft iron wire cut into suitable lengths and made into a bundle of the requisite size. The most suitable sizes are Nos. 18, 20 and 22. The wire must be made of the best soft iron well annealed. If not quite soft when bought, or if hardened whilst being made straight, the bundle of wires must be made red hot and allowed to cool down gradually through several hours whilst buried in hot ashes. The wires for the core should be all cut to equal lengths of about from ½ to 1 inch longer than the extreme length of the coil bobbin, so as to have quite ½ an inch protruding at one end of the coil, to form a pole piece for attracting the armature of the break hammer, and each piece of wire must be quite straight.

A most convenient method for making a round bundle of these wires is as here directed. Procure a smooth tube of brass, iron, or glass, having a diameter equal to that of the required coil, and a length equal to that of the coil bobbin. Pack this tube closely and tightly with the straightened iron wires. If the core is intended for a medical coil with a brass tube sliding over the core to regulate the tension of the induced current, it will be advisable to use this tube as a receptacle for the wires of the core. When the tube is quite full of wires, wind a few turns of binding wire around the protruding end, and get it nicely rounded. When this has been done, dip the ends for a few moments in a saturated solution of copper sulphate, to coat the wires with metallic copper, then for a few moments into a saturated solution of zinc chloride (killed spirits or soldering fluid), then give a momentary dip in a ladle of melted solder, just long enough to solder all the extreme ends together, the surplus solder being wiped off with a greasy rag. The bundle of wires may now be withdrawn gradually from the tube, whilst some twine or wire is wound around the bundle to keep the wires in their places. The opposite end may now be dipped in the coppering solution and soldered, then the whole bundle must be well soaked in hot melted paraffin. If the core is for a spark coil, the solder may be omitted, and the whole bundle of wires bound with soft cotton or with tape, from end to end, as it is being withdrawn from the tube. This binding must be laid on smoothly, as it will form the body on which the primary will be

wound if used for a small coil, and will not be disturbed after the core has been soaked in the paraffin, the paper to form the body of the coil bobbin being wrapped direct on this covering of the core. The principles advanced in § 3 will here come into practice. The core must be well insulated (and there is no better insulator than paraffin wax for the purpose), but it must not be over insulated. The insulating covering of the core must therefore be as thin and yet as perfect as possible, for much of the magnetic inductive effect will be absorbed in a thick coating. The coating must be smooth on the outside, so as to fit tightly into the tube of the bobbin body, since badly fitting parts will enclose air, and this is a bad conductor of inductive energy. In a medical coil it is desirable to have a thin air space between the core and the inner surface of the coil bobbin (in which the regulator works), but, in a spark coil, every fraction of inductive energy must be utilised to increase the tension of current in the inductive circuit, *i.e.*, in the secondary coil. The core of a spark coil may be built up in the paper tube to form the body of the coil, and the whole tube (with the core enclosed) soaked in the paraffin, but, if this method is adopted, there will be a little difficulty experienced in winding the coil, unless a special form of coil winder be employed. If the core is thus built, it need not be bound with wire before soaking it with paraffin. If the wires are hard and need annealing, they must not be soldered at the ends nor bound with twine, but must be closely wound, as withdrawn from the tube, with fine

soft iron binding wire. After the bundle has been annealed, the ends may be soldered and then soaked in paraffin wax as directed above.

When the bundle of wires has been thoroughly permeated with the melted wax, it should be set on end to drain off the surplus and get hard. The soldered ends may now be capped, to give them a neat appearance. If they are not soldered, they are painted with sealing wax varnish for the same purpose. Some makers enclose the protruding end in an iron cap, to form a solid-looking pole piece. If this is done, care must be taken to have the cap well annealed before fixing it on the core. The ends of the cores for medical coils

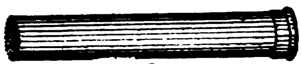


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FIG. 9.—Core for medical coil, capped with brass.

where a separate magnet is used for the break, may both be capped with brass, a brass socket being sweated on to the soldered end of the core at one end, as shown at Fig. 9. The flanges of this socket will prevent the core from being pulled out when the regulator is being withdrawn. When cores are built for a medical coil with a regulator, they may be fixed at one end into the body of the coil bobbin in the following manner:—Either make the hole in the bobbin end small enough to exactly fit the end of the core, and fix this in the wood with some good hot glue, or glue a strip of paper around the end of the coil until it fits the body of the bobbin, and thus secure it firmly with glue. It is

advisable to place the core in the regulator, and put this also into the body of the bobbin (interposing a few turns of greased cotton between the end of the regulator tube and the glued end, to keep them from sticking together), and thus insure the core being placed in a central position, where it must be allowed to set firm before the tube is withdrawn. In some coils the core itself is made to be withdrawn from the tube, and thus form a regulator.

§ 11. PARAFFIN.—As this insulating substance is a most important one to the coil maker, and will be frequently mentioned in subsequent sections, as it has in previous ones, a few words respecting its composition will not be out of place here. Paraffin is a substance resembling white wax (*i.e.*, beeswax bleached white) in colour and general appearance. It differs from white wax in being harder and free from flavour and odour. Even when it is burning, the odour from it does not resemble that of beeswax, nor is it that of paraffin oil, or of fat. It has a slight resemblance to stearine, but differs from this substance in being free from its tallowy odour, and having a closer grain than stearine. In the best samples (and these should only be used as insulators for coils) paraffin is whiter, denser, and harder than stearine. A thin cake of paraffin is slightly sonorous when struck, and is less brittle than white wax or stearine. It is named paraffin wax in this and other works wherein it is recommended as an insulator, because there is a tendency in the public mind to confound the directions for using this with preconceived

ideas respecting paraffin as an oil, the only form of paraffin generally known. It has also been named solid paraffin to distinguish it from paraffin oil. As there are some ten different substances known to chemists as paraffins, the public may be excused for mixing two of these in their ideas. Paraffin wax is so-called because of its resemblance to white wax, but the most correct name is *paraffin.* It is a hydro-carbon, obtained as a by-product in the distillation of coal and rock oil. It will readily melt over an ordinary fire, but should not be placed in a vessel in direct contact with the flame, as this will be liable to fire the paraffin, and thus cause an unpleasant smoky odour. It should therefore be heated on a steam or water bath, as glue is heated. A most convenient method for amateur coil makers is here described:—Make a tripod—*i.e.*, a three-legged frame—out of some stout iron wire ($\frac{3}{16}$ inch in diameter) to stand over a small spirit lamp. On this place a tin baking dish containing boiling water, and in this stand another shallow dish containing the paraffin in shreds or shavings. Light the lamp to keep the water hot, and in a short time the paraffin will melt to an oily liquid. In this the core or wire may be immersed, and the whole kept hot for any length of time without fear of burning the paraffin. Coarse wires are best coated with paraffin by first making the required length into a hank of a size suitable for immersion in the vessel containing the melted paraffin. Fine wires must be run through the hot wax, and this may be done by running the wire under a brass pulley held in the bottom of the

dish, on a metal hook, soldered to a plate of sheet lead. If a tin dish is used to melt the paraffin in, this hook may be soldered to the bottom of the dish. The wire may be made to pass under two such pulleys thus fixed in the bottom of the dish. Fine wires should be run off a bobbin revolving on an iron wire, held over the vessel, under the pulleys, and on to another bobbin fixed on a revolving spindle over the other end of the vessel.* This is done to avoid abrasion of the wire covering by scraping the edges of the vessel. The spindle may be revolved with a small winch handle, or by means of a piece of bent iron wire, if a proper winding machine is not available. The wire may be guided on by hand, passing it through a scrap of rag held between the finger and thumb of the left hand. The hot paraffin will soon set and cool, when it will peel off the fingers without soiling them, as it is not really oily or greasy, although it has this appearance. When the wire has passed through the hot paraffin, the bobbin containing it may be put in a warm oven, when the wax will soak well into the silk covering and complete the insulation. Paraffin may be melted in an oven instead of in a water bath, but this is not so convenient a method as that just recommended.

§ 12. THE PRIMARY WIRE OF THE COIL.—This, as its name implies, is the first wire wound on the core of the coil; it forms the wire of the first coil, and gives its name to the primary current from the coil. The wire employed should be of the best annealed copper, well coated with

* The commencing end of the wire should be brought out through the bobbin end, to provide a connection for testing the continuity of the wire.

silk. Cotton-covered wire may be employed, but should not be used if silk-covered wire can be obtained, since cotton is an inferior insulator to silk, the fibre is coarser, and the coating is thicker. Considerations for the purse will sometimes influence coil makers, and lead them to select cotton-covered wire for the primary, but the difference in price between silk and cotton-covered wire, from Nos. 16 to 20, only amounts to 1s. 6d. per lb., and this slight difference should not influence the maker who wishes to make a good spark coil. The inductive effects of the current are increased by the number of turns of wire we can get in a certain space, and more turns of silk-covered wire can be got on a core than of cotton-covered wire.

In making medical coils, where a high tension current is not desired, and the primary is intended to be used together with the secondary wires, a smaller wire than No. 20 may be employed, and here the price will rise to double that of cotton-covered wire. As larger quantities of this finer wire are used for the primary of a medical coil, it may be desirable, when a question of cost comes in, to employ cotton-covered wire.

The size of wire selected for the primary wire of a coil is determined by:—1. The effects desired from the coil; and, 2, the intended size of the coil. If the coil is intended to be used as a spark coil, to give long and thick sparks at the ends of the secondary wires, a full volume of current must traverse the turns of the primary wire, and this can only be carried by a large

wire. But, if the wire is too thick, it will be very stiff even if well annealed, and we shall not be able to wind it close to the core. As a consequence we shall lose power through loose winding, creating air space between the core and the coil. Then, too, the length of the spark will be influenced by the magnetic intensity of the core, and this will be increased by the number of turns of wire we can get in close proximity to the core. If we use a short, thick wire with few turns, the magnetic influence will be less than when using a smaller wire, and winding on more turns in the same space, the magnetism of the core being proportioned to the ampère turns we can get around the core in a given space. This term "ampère turns" requires a word or two of explanation. If one ampère of current be sent through one turn of wire wound on an iron core, a certain amount of magnetism, so to speak, will be formed in the iron. If we wind another turn of wire around the core, and still send 1 ampère through it, we get a 2 ampère amount of magnetism in the core, or an effect equal to that obtained from 2 ampères sent through one turn of wire. Now, providing always that the same volume of current is forced through the wire, we shall increase the magnetism of the core to the value of 1 ampère more for each turn of wire we get on the core. Thus, 1 ampère sent through 10 turns of wire will develop 10 ampère values of magnetism, and 100 turns of wire will develop 100 ampère values in the same core. But the magnetic value of the turns of wire decreases with their distance from the core when the

total thickness of the coiled wire reaches three times the diameter of the core. This thickness, however, is not reached in the primary of an induction coil for giving sparks, because other considerations, based on experience, forbid an increase of turns beyond some four or six layers of wire. These are, principally, the inductive effects of the turns of wire on each other, known as the "self-induction of the primary coil." It has been shown that a current of electricity passing through a wire lying parallel to another, induces in that wire another current passing in the opposite direction. This inductive effect is always present in the primary of an induction coil, and hinders the charging process of the current; for, all wires, acting as conductors of electricity, take time to charge them. An appreciable quantity of time is required to completely charge, or to fill, so to speak, the primary wire with current, and an equal length of time is taken to discharge the current. This time is extended with the length of wire employed in the primary, but cannot be fulfilled in a long coil, because the magnetic action of the core or of the electro-magnet employed in the automatic interrupter, interferes to interrupt the current before the wire is fully charged. There is, therefore, no advantage in having a very long primary wire unless a very slow movement of the automatic interrupter can be insured, since the back inductive current hinders the charging of the coil, and the result is shown in short, thin sparks at the terminals of the secondary. These back effects are, to a certain extent, absorbed in a properly-constructed condenser, as shown

in § 23, but are not wholly provided for in a condenser, however well constructed. The lengths and sizes of primary wires found by experience to be most suitable for small spark coils are given in the Table on Dimensions of Spark Coils, § 21.

§ 13. WINDING THE PRIMARY COIL.—This may be regarded as a simple mechanical process, not requiring any large amount of skill. The primary wire should be first examined closely to detect flaws in the insulated covering. These, when discovered, must be repaired with a thread of soft silk dipped in melted paraffin, and wound around the defective spot. The whole length of wire should then be made into a coil or hank, immersed in melted paraffin until the insulated covering is permeated with the wax, then the coil lifted out of the vessel and hung above it to drain off the surplus wax. The coil of wire may then be wound back on a wooden bobbin, from which it will run when winding it on the bobbin of the coil, or may be wound direct on the bobbin to form the primary coil, from a suitable apparatus for holding the wire. The best apparatus for holding an open coil or hank of wire whilst it is being transferred to a bobbin, is the swift in use among wire-drawers and wire-workers. This is made of a disc of wood from 4 in. to 8 in. in diameter, as may be required, and from $\frac{3}{4}$ in. to 1 in. in thickness. A hole is bored in the centre, and bushed with a bit of brass or of iron tube to fit an iron spindle, and a number of $\frac{3}{8}$ in. holes are drilled, as shown at Fig. 10, to receive the rods of some tough wood on which the hanks of

wire will fit. The apparatus will revolve on an iron spike driven into a bench, a stout collar or washer being placed on the spike beneath the swift to keep it up off the bench, as shown in section at Fig. 11. The next best thing to this is a heavy stoneware bottle without handles, filled with water, the hank being placed over the bottle and the wire run off as a spiral over the top.

Before winding the primary wire, it will be advisable to prepare a few slips of paper soaked in paraffin, to place between the layers of wire, and thus insure the perfect insulation of one layer from another. Select a

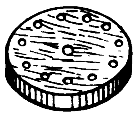

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FIG. 10.—Bottom disc of wire-worker's swift.

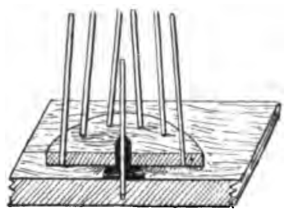

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FIG. 11.—Section of wire-worker's swift.

tough but thin white paper, free from flaws and acid. Cut this into strips wide enough to cover the whole layer of wire, and long enough to go twice or more around the coil. Place the strips in a shallow dish, or on a plate, with shavings of paraffin between the layers, and put the whole in a moderately heated oven until the wax has melted and soaked into the paper. Then remove the paper, one sheet at a time, whilst hot, lifting up each sheet by the corner with a pair of forceps (made of a strip of tin bent double, if nothing better

is at hand), and hang each strip on a line of stout twine to drain and dry. This will only occupy a few minutes.

Mount the bobbin, for the coil, in a lathe or on a coil-winder, and get it to run quite true. Bore a hole (obliquely through one of the bobbin ends from the inside down close to the body), large enough to pass an end of the primary wire. Pass about 7 or 8 inches of the wire out through this hole, wind the protruding end around a pencil to form a helix, and secure the wire firmly in the hole with a drop of sealing wax. Wind the wire on the body of the bobbin firmly and regularly, each turn close to another as a reel of cotton is wound, until the opposite end is reached. Now lay a strip of prepared paraffined paper on the coil and envelop the wire already wound with one or two layers of the paper, then wind on another layer of wire, bore another hole in the same bobbin end, but opposite to the first hole, cut off the wire so as to have about 8 in. free, pass this through the hole, draw it tight, secure it with a drop of sealing wax, then make it into a helix like the first end. These helices of wire will prevent the ends from flying about whilst the secondary wire is being wound. When the coil is finished, these ends will pass down through the base-board, and be connected, one to the terminal pillar in connection with the battery, and the other to the foot of the break spring or the spring of the rheotome, as it is named by some makers. The outside of the primary coil may now be basted with hot paraffin and made quite smooth by running it around under the fingers. It must then be covered with three or four

layers of paraffined paper well basted with hot paraffin and smoothed down ready for the secondary wire. This should be done for all coils, even the smallest. A few more layers of paper may be put on for larger coils, but care must be taken to avoid over-insulation by having too much insulating material between the primary and secondary wires. In large coils, special attention must be paid to the quality of the paper, which must be quite free from any flaws or pinholes. These may be detected by holding the paper up to a strong light. As the tension of the induced current will be highest at the ends of the bobbin, we may give these parts an extra layer or two of paper to strengthen the insulation at these parts. In making very large spark coils to give sparks from 6 in. upward, where the coil bobbin and ends are made of ebonite, it is advisable to have the tube of the bobbin body large enough to enclose both the core and the primary coil. The primary wire is then wound over the core, previously fitted with ebonite flanges, and both fitted into the body of the coil after the secondary coil is wound. See instructions in § 38. Some makers of coils employ beeswax instead of paraffin wax as an insulator of the primary, and to saturate the insulating folds of paper, but this material is an inferior insulator to paraffin, and liable to an acid reaction which in time will injure the silk and the wire. Others make a mixture of beeswax and black resin for the same purpose. The resin is first melted in an old pot, then the beeswax is added until the mixture is deemed to be sufficiently liquid, when it

is applied to the coiled wire, hot, with an iron spoon, whilst the coil is kept slowly revolving. Others prefer shellac lacquer or varnish laid on the coils after they are wound, and on the insulating layers of paper. Another insulating substance used for the same purpose is a varnish made of sealing wax dissolved in warm methylated spirit. The mixture of resin and beeswax has been highly lauded, but it is much inferior to paraffin as an insulator, and is liable to crack in cooling. Both this and the varnishes mentioned, possess, in common, the serious defect of cementing the coils of wire together, and thus rendering the wire useless should any future repairs be necessary.

§ 14. THE SECONDARY WIRE OF THE COIL.—This, as its name implies, is the second coil of wire wound on the core, over the primary wire of the instrument. In spark coils it is entirely separate from the primary wire, not being connected in any way to the first coil. The effects produced in this coil (that is, the electric current generated in it) are therefore purely inductive, being induced by the current circulating in the primary coil. The induced current generated in this coil, will pass in an opposite direction to that of the inducing current in the primary coil. It will also have only a momentary existence in one direction, when the circuit of the primary coil is made, and an even less transient existence in the opposite direction when this circuit is broken. The induced current has, therefore, a see-saw alternating movement backward and forward whilst the flow of current in the

primary circuit is being interrupted. Its whole action, and the effects obtained from it, are dependent upon the perfection of the interrupting apparatus. The volume of current induced in the secondary wire of a spark coil is always small, and is governed by the size of wire employed. The tension of the current is always higher than that of the inducing current, or that of the induced current in the primary coil, and is governed by the length of wire employed, together with the number of turns wound over the primary wire. The length of the spark obtainable from the terminal of the secondary wire of a spark coil is largely determined by the length of wire employed in the secondary coil. This, in itself, does not wholly determine the length of spark, which is also controlled by the condenser, and also the "break" of the instrument. The length of spark is also influenced by the insulation of the coil, and the skill employed in winding the wire. If the wire is badly insulated, there will only be a short spark, or no spark at all, since the tension of the induced current will be absorbed in the wire, instead of being conveyed to the terminals. Or, put in another way, the stress of the charge will be distributed among several conductors instead of being concentrated in one. If the wire is over-insulated with too much insulating material between the coils and the layers of wire, the turns of wire will be far apart, and will only feebly influence each other: they will also be widely separated from the most intense field of inductive influence, and space will be taken up with insulating material which ought to be occupied with wire. The

result will be a shorter spark than that for which the coil was built. The rule followed by amateur coil makers is to allow a mile of No. 36 silk-covered copper wire for each inch of spark desired from the coil. Some results of actual experience are given in tabular form in § 21, and from this it will be seen that it takes more than 1 mile of No. 36 B W G copper wire to give an inch spark from a moderate size coil, and more than 11½ miles of No. 36 to give a 6 in. spark. This goes to prove that the inductive influence of current tension decreases with the distance of the wire turns from the core of the coil. Although the extra turns of wire on the outside of the coil do increase the tension of the induced current, they do not increase it in the same proportion as the turns of wire nearer the core. But, all other circumstances being taken into consideration, the rule holds good, that, to obtain a long thin spark from a coil, we must employ a long thin wire in the secondary coil.

The tension or potential of the induced current at the terminals of the secondary coil may be calculated from the following rule given by Dr. R. M. Furguson.* "The total electro-motive force of the coil is the same of that of all the turns in it, in the same way that the electro-motive force of the battery is proportionate to the number of cells." If, therefore, we can find the voltage of the current flowing through the primary wire of a coil, and the number of turns made by the secondary wire, then multiply the turns of wire by the voltage or

* "Electricity." By Dr. R. M. Furguson. Pp. 177-8.

E M F of the current, we shall get as a total the E M F of the current at the terminals of the secondary. By the same rule also, we can plan a coil to give a predetermined length of spark at the terminals if we reckon on 50,000 volts as being necessary to give a 1 in. spark in air. In all these calculations, however, due regard must be had to the build and conformation of the coil, the capacity of the condenser, and the insulation of the wire.

The volume of spark obtainable from a coil, is governed by the size of wire used in the secondary coil. To obtain a large bushy spark, we must use a larger wire, and, if a long but bushy spark is desired, a greater length of the coarser wire must be used than of the finer wire. For instance, if in using 1 lb. of No. 36 for a secondary wire we get a $\frac{3}{4}$ in. spark, and we wish to get a bushy spark of a similar length, it will be necessary to wind on $1\frac{1}{2}$ lbs. or more of No. 34 wire to form the secondary coil.

§ 15. DEFECTS IN FINE SILK-COVERED COPPER WIRES.—The wire employed in winding the secondary of a spark coil must be made of the best high conductivity copper, well annealed, well insulated with a close covering of silk, and of continuous conductivity throughout from end to end of the length of wire employed. If the wire is made of inferior metal, it will offer a useless resistance to the current. If it is not annealed soft, and this defect will be shown by its stiffness and springy behaviour when wound around the finger, it will also offer a useless resistance to the cur-

rent and be liable to break off short whilst being wound and twisted about. Resistance to the current is offered by each turn of wire wound on the coil, but, as each turn induces a higher tension in its neighbour, this resistance is useful. The resistance offered by hard wire and bad joints only increases the temperature of the coil, and thus causes part of the electric energy to be absorbed as heat. If the wire is imperfectly insulated, that is, if the copper can be seen between the layers of silk, or the silk covering slips aside when the wire is pinched between the finger and thumb, it will be useless for a spark coil. Neighbouring turns and layers thus imperfectly insulated will be sure to establish communication with each other at some time, and thus cause a break-down. Running the wire through paraffin may insulate such defective spots, but the coil maker runs a risk in using such wire. If the wire has any breaks or knots it will not conduct the current at all. It sometimes happens that a fine wire, such as No. 40 silk-covered copper wire, gets subjected to too much strain whilst it is being wound on the reel or spool on which it is sold; or a kink is made in the wire, which snaps as it is being made straight. The wire will then break, but the silk covering will hold the two parts together. This wire is useless until repaired. Another cause of non-continuity in conduction arises from badly-made knots. It is too much to expect wire drawers to draw several miles of fine copper wire in one length without breaking, but, when it breaks and a knot is made, it must be a good knot, made with a view to

perfect electric conductivity, or it will be useless for a spark coil. The knots usually made by wire drawers are the ordinary weaver's knot, or else the becket hitch; if these are not made good and soldered whilst covering the wire, they work loose, the paraffin gets in between the points of contact and the wire is rendered useless. All such knots should be cut out, the ends of the wires bared and cleaned, then twisted together to form a long splice, and the joint dipped in molten solder. This should be done before the wire is covered with silk. Such knots must be searched for, and when discovered by the coil maker they must be similarly repaired, and insulated with paraffined silk wound on by hand. When the winding of the wire is entrusted to unskilled or careless hands, it may get broken in winding, and the broken ends simply tied together. Such a knot fully insulates the two lengths from each other, rendering them both useless until the badly-made knot has been discovered and repaired. These warnings respecting the possible defects of fine covered wires all point to the necessity of examining closely each spool of wire whilst running it from one spool to another before it is run through paraffin.

§ 16. How to Discover Defects in Wires.—It needs a trained eye to detect defects in insulation and bad knots and non-continuity in conductivity whilst the wire is running from one spool to another, even when turned slowly. The detection of these faults is facilitated in the following manner. Pass the commencing end of the wire through a hole in the end of the bobbin,

reel, or spool on which it has to be wound, and solder it to the metal spindle on which the spool is mounted. Or fit a brass cylinder on the spindle with the spool, and solder the wire end to this, or clip the end in a screw clip on the cylinder. A brass spring must now be fixed to press on the spindle or the cylinder, and this spring must be connected to the terminal of a tolerably sensitive galvanometer. The wire in its passage from one spool to another must also pass over a brass rod or roller running on a metal spindle mounted on metal bearings connected in circuit with a battery and the galvanometer. The wire should bear with some weight on the rod, so as to make good contact, but not enough to abrade the silk covering. A bare spot will announce itself at once, as it will close the circuit and cause a deflection of the galvanometer needle. Every knot should be tested, and the continuity of the wire at each knot be similarly tested. If the needle of the galvanometer does not move when a bared part of the wire is in contact with the brass rod, we may expect a break or a bad knot, and must turn back until it has been found. A battery of several very small cells should be provided for testing, and only one used at the start, the number of cells in circuit being increased with the length of wire wound on the receiving spool. By adding cell to cell in series we shall get the force necessary to send current through the higher resistance of a long length of fine wire.

§ 17. WINDING THE SECONDARY COIL.—The wire selected for the secondary coil, having been examined

and tested as directed in sections 15 and 16, then coated with paraffin as directed in section 11, we may now make arrangements for winding it on the primary to form the coil. The surface of the primary coil must be first examined and smoothed if the secondary wire is to be wound on this direct. The same precaution must be observed if the wire is to be wound on a separate bobbin, as the body of this must also be quite smooth. We shall also need a large number of thin paper strips paraffined as directed for the primary in section 13. Very thin and very tough paper should be selected for this purpose, as the insulation between the layers of wire must be as thin and as perfect as possible. Examine each strip for flaws and pinholes by holding it up to a strong light, and reject all that show the least flaw or pinhole.

The secondary wire must be wound in the same direction as the primary wire. A fine hole should be pierced through the bobbin end through which the commencing end of the primary passes, and about 8 in. of the commencing end of the secondary passed out through this hole. The piece of wire thus passed out should now be wound around a small pencil to form a helix, or spiral curl, and the wire secured in the hole by a touch of hot sealing-wax. The reel containing the fine wire should be placed on a spindle running in bearings on a pair of standards placed about 2 ft. to the left of the coil winder. A piece of stout twine attached to a lead weight should hang over the spindle to act as a brake and thus prevent the fine wire from

over-running and forming kinks. Wind on the wire carefully, guiding it on with each turn close to the last in regular turns as a reel of cotton is wound. A little knack or skill of the left hand, acquired by practice, is necessary before this can be properly done. The process is facilitated if the operator will keep his guiding hand at a few inches' distance from the coil and allow the wire to guide his hand as it touches the turn of wire already wound. When the first layer is on, warm one of the strips of paraffined paper and smoothly cover the layer of wire with one or two layers of paper. The paper should be slightly wider than the bobbin, so as to form a flange on each side and thus insure a thicker insulation at these parts where insulation is most needed. This will also be improved if some hot paraffin can be basted on the last few turns of wire. Each layer of wire must be thus wound and insulated, and in this way the secondary coil is formed. The finish end of the wire should be brought out through a fine hole in the opposite bobbin end to that which holds the commencing end of the wire, and coiled into a helix to keep it from injury whilst other parts of the instrument are receiving attention. These coiled ends will be then straightened, and attached to the terminal pillars of the discharger.

Whilst winding the fine wire for the secondary, pay special attention to kinks, that is, loops of wire or snarls drawn tight. If these form, do not wind them on the coil, but carefully straighten them out by turning the loop back. Do not pull it straight. A kink thus taken out will cause a hard spot in the wire, having a high

resistance, and, in attempting to pull the kink straight, the wire may be ruptured. It is preferable to have a soldered joint instead of a hard kink in a coil. With proper care, however, the formation of kinks may be avoided.*

§ 18. A Coil Winder.—A coil may be wound in a lathe if the operator has attained some skill in winding, but the tyro and amateur may find some difficulty in winding regularly on a lathe, or he may not have a lathe. A wheel, like the old-fashioned spinning wheel of our ancestral mothers, may be employed to turn the spindle, if such wheel is attainable. Failing this, either of the following arrangements will do equally well, if not better, in the hands of an amateur, and can be easily made out of a few waste materials.

If the primary is wound on a separate bobbin apart from the core, and this is to be placed in the coil after winding it, or, if the secondary is to be wound on a separate bobbin, the following arrangement will serve the purpose of a coil winder. Procure two stout iron brackets—L shape—tall enough to suit the diameter of the coil. Drill two holes in the foot of each, for screws to hold the brackets firmly on a bench, and a $\frac{3}{8}$ in. hole in each near the top, to form bearings for the spindle. Make a spindle and winch handle combined, out of a $\frac{3}{8}$ inch rod of iron; fit two corks or bungs centrally on this. Measure the length of the coil bobbin, and screw the brackets down to a bench at the same

* The secondary of a large spark coil to give sparks of over 6 in. must be wound in a special manner, as described in section 37.

distance apart as the length of the bobbin and the thickness of two thin washers or collars. Fit the two corks or bungs in the ends of the bobbin tube, place the bobbin between the brackets with one of the collars near the winch handle end of the spindle, pass the spindle through the bearing hole of one bracket, then through the plugs in the bobbin, through the collar at the other end, and through the bearing hole in the other bracket. This arrangement is shown in the sectional diagram, Fig. 12. The bobbin may now be revolved by

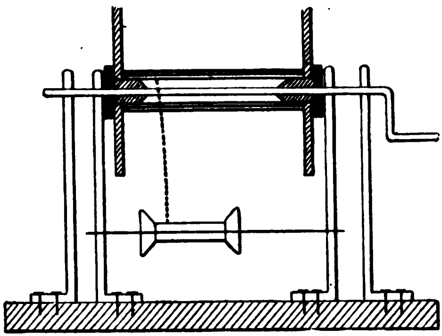


FIG. 12.—Sectional diagram of coil-winder.

the winch handle and the wire wound on. The collars on the ends are intended to insure free rotary motion of the bobbin and to prevent end shake, as this will interfere with accurate winding of the wire.

If the primary is wound direct on the core, and this forms the body of the bobbin, another method must be adopted to revolve it. Two brackets should then be employed at each end, and placed from 1 in. to 1½ in. apart so as to form long bearings, to prevent wobbling,

the foot of one bracket being turned in the opposite direction to that of the other bracket. Two discs of hard wood must now be procured, one of which must be fitted with a short spindle to go in one of the bearings, and the other with a spindle ending in a winch handle. The brackets and discs should now be placed at a sufficient distance apart to allow the coil bobbin to be fitted tightly between them, and then fixed in this position by three short screws passing through each disc into the ends of the bobbin. Care must be taken to have the bobbin run true, and end shake is prevented by collars placed outside the discs. These rough contrivances may make way for more finished productions, made on similar lines, if the skill and means of the coil maker will allow of it being done.

§ 19. THE INTERRUPTER, VIBRATOR, BREAK, OR RHEOTOME.—The little mechanical arrangement for automatically interrupting the flow of current in the primary coil is called by one of these names. It is named an interrupter because it interrupts the even flow of the current. It is named a vibrator because the spring vibrates rapidly to and fro as contact is made and broken between the platinum-tipped screw and the spring. It is named a break because it serves to break the continuity of the current in the primary circuit. By makers of medical coils it has been named a rheotome, a word made up of two Greek words—*rheos* a current, and *temno* I cut. It is made in different forms, each suitable to the instrument for which it is designed, or to suit the fancy of the coil maker. The best forms are

those actuated by electro-magnetism, which may be either the magnetic energy of the core or that of

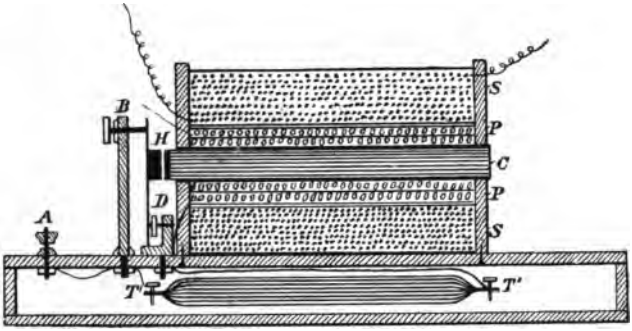


FIG. 13.—Section of a small spark coil.

A.—Battery Terminal. *B.*—Break Pillar. *C.*—Core. *D.*—Break Spring. *H.*—Break Hammer. *P.P.*—Primary. *S.S.*—Secondary. *T.'T."*—Terminals of Condenser.

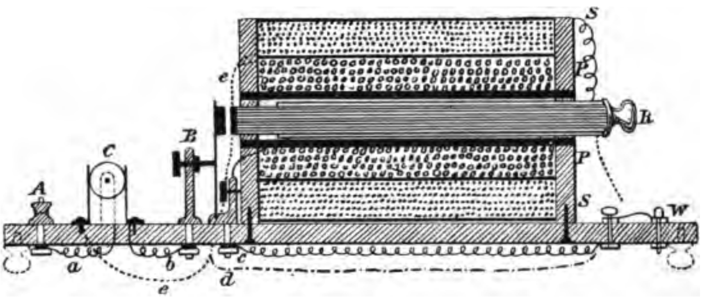


FIG. 14.—Section of a small medical coil.

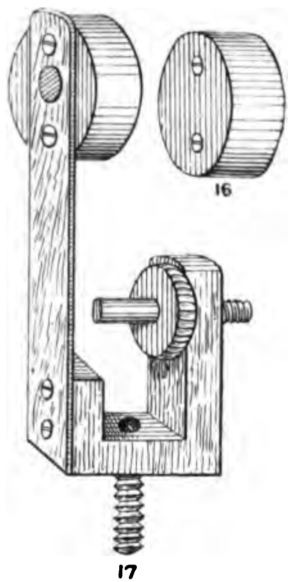
A.—Battery Terminal. *B.*—Break Pillar. *C.*—Commutator. *P.P.*—Primary. *R.*—Regulator. *S.S.*—Secondary. *W.*—Switch.

a.—Wire connecting Terminal to Commutator. *b.*—Wire from Break Pillar to Commutator. *c.*—Wire from Foot of Break Spring to Switch. *d.*—Branch Wire from end of Primary to Switch. *ee.*—End of Primary connected to Spring of Commutator.

a separate electro-magnet. For small spark and medical coils, the break is made to be worked by

the magnetism of the core, as shown in Figs. 13 and 14.

In this form there are six essential parts, viz., the hammer, contact spring, bracket for spring, regulator, pillar, and contact screw. The shape, size, and disposition of these parts vary with the size of coil and its designed use. The hammer-head, Fig. 16, may be merely a slice cut off from a bar of soft annealed iron with a hack-saw and filed to take off the rough edges. Some makers round the pane of the hammer, and others give it a coned form. Two small holes should then be drilled and tapped in one of the faces as shown, to take two small screws fastening the head to its spring as shown at Fig. 17. The hammer-head should have a diameter equal to that of the core, and a thickness proportioned to the length of the core, ranging from ¼ in. up to ¾ in. for the largest. It should not be cut with a cold chisel nor hammered, as this tends to harden the



FIGS. 16 & 17.—Break Spring and Hammer.

iron. The contact spring may be of spring brass or of German silver, ranging in length from 1½ to 6 or more inches, and in width from ⅜ up to ½ inch to suit the size of coil for which it is to be used. The spring for a spark coil should extend beyond the hammer to a length of 1 in. or more. The hammer-head is therefore fastened to the spring opposite the end of the core, and about one-third down from the top of the spring, as shown at Fig. 13. The contact is made near the top of the spring. By this arrangement, the part of the spring to which the hammer is fastened, is made to bulge toward the core before contact is broken at the top, and this allows the core to be fully magnetised before contact is broken. As a result, the spark from the secondary coil is longer and fuller than when contact is made close behind the hammer, and the spark at the break is reduced in length. The spring for the rheotome of a medical coil should be short, the contact made below rather than above the hammer, and all the parts so arranged as to make and break contact very rapidly. Many persons suppose the current from a coil to be beneficial to the nerves when the break works with a jerky movement so as to cause violent contraction and relaxation of the muscles. This is a popular error, the opposite being the truth. When the break of a medical coil works smoothly and rapidly, and the patient does not feel any violent jerks, then, and only then, is the current being properly applied, as far as the working parts of the apparatus are concerned. Figs. 14 and 17 show a simple spring and hammer for a medical coil

when the break is worked by the magnetism of the core. Fig. 40 shows the form of a spring and hammer for the separate type of rheotome actuated by an electro-magnet outside the coil. A speck of platinum must be soldered to the point of contact at the back of the spring, or a tiny rivet of platinum, having a broad head, must be put into the spring at the point of contact. As platinum is the most infusible and non-corrodible of all metals, it is least susceptible to the corroding action of the electric spark passing between the two points of contact in the rheotome of a coil.

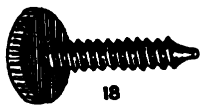


FIG. 18.—Contact Screw for Break.

The spring is sometimes secured to a pillar by a screw, as when the spring is held in a horizontal position,* or it is let into the foot of a bracket and soldered as shown at D, Fig. 13, or it is secured to the foot of the bracket by screws as shown at Fig. 17. In both spark and medical coils it is most important to have a regulator to adjust the distance of the hammer from the face of the electro-magnet. This is effected in the vertical spring by a set screw in the bracket, as shown at Fig. 17. This screw must fit tightly in the bracket. In the horizontal forms this means of regu-

* The spring is held out as an arm from a contact pillar at the side of the core in the cheap French coils. This is a very good arrangement.

lating the play of the spring is omitted, the spring being bent to give it an upward tendency which is kept down in its proper position by the contact screw. The contact screw is a brass screw with a milled head, as shown at Fig. 18. A small hole is drilled in the end of this screw to take a tiny end of platinum wire which is

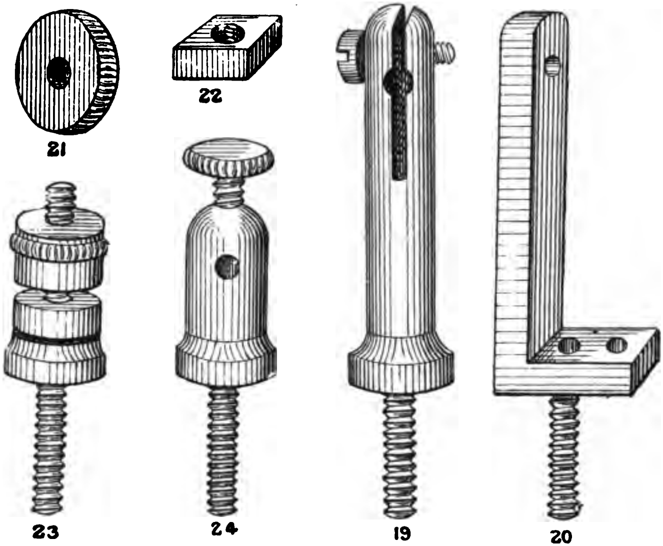


FIG. 19.—Break Pillar. FIG. 20 —Bracket Pillar for Break. FIG. 21.—Lock Nut. FIG. 22.—Small Brass Nut. FIG. 23.—Binding Screw, Telegraph Pattern. FIG. 24.—Pillar Binding Screw.

fitted and sweated into the hole and allowed to project $\frac{1}{16}$ in. This screw is held in position opposite the contact spot on the spring by a brass pillar made as shown at Fig. 19, or a brass bracket as shown at Fig. 20. A slot is cut in the top of the pillar after the hole for

the screw is drilled and tapped, and this is intersected by a hole carrying a brass set screw, to tightly clasp the contact screw and keep it from jarring loose. If this plan is not adopted, the screw should be fitted with a lock nut, shown at Fig. 21. A screwed tang should be fitted to all brackets and pillars, and this tang should be long enough to pass through the base board of the coil and be held beneath by a small nut shown at

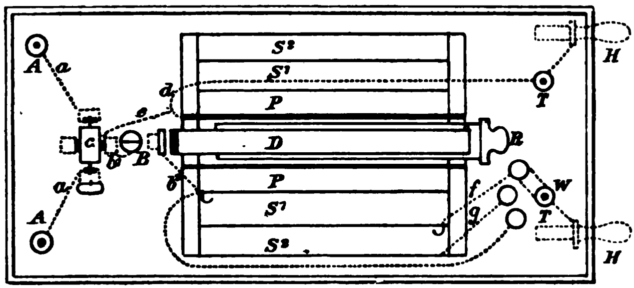


FIG. 15.—Plan of Medical Coil, showing connections.

A.A.—Terminal Binding Screw. *B.*—Break. *C.*—Commutator. *D.*—Core. *H.H.*—Handles of Rheophores. *P.P.*—Primary Wire. *R.*—Regulator. $S^1.S^1.$—First Secondary Wire. $S^2.S^2.$—Second Secondary Wire. *T.T.*—Secondary Terminals. *W.*—Switch. *a.a.*—Course of Wire to Commutator. b^1.—Wire to the Break Pillar. b^2.—Wire from Break Spring. *c.*—Commutator. *d.*—Branch Wire from Primary. *e.*—Wire from Spring of Commutator to Primary. *f.*—End of First Secondary. *g.*—End of Second Secondary Wire. *h.*—Branch Wire from Primary to Switch.

Fig. 22. When thus fitted, all wire connections can be made beneath the base board and be secured, with nut and collar. These are the more simple forms of rheotomes. Others will be noticed in the next chapter, when coil accessories will receive attention.

§ 20. FIXING THE COIL ON ITS BASE.—This may be done by means of brass screws passing up through the base into the bobbin ends. Or, when a round end

with a groove cut in it has been employed, as shown at Fig. 8, the ends of the coil are strapped down with two pieces of catgut passing through holes in the base board and knotted beneath. After the coil has been fixed, the rheotome may be put in position, the terminal binding screws fixed, and the connecting wires of the primary, together with their branches, led to their assigned positions, as shown in plan at Figs. 2 and 15.

§ 21. DIMENSIONS FOR SMALL SPARK COILS.— The following results of experience have been kindly supplied me by Mr. S. R. Bottone, Carshalton, Surrey, and will serve as a guide to makers of small coils. I have arranged the dimensions in tabular form.

TABLE OF DIMENSIONS FOR SMALL SPARK COILS.

Length & diameter of Bobbin.	Length & diameter of Core.	Primary.		Secondary.		Condenser.		Cells of Battery in series		Sparks obtained.
Inches.	Inches.	No.	Layers	No.	Wgts	Sheets	Area	No.	Capcy.	Inches.
							" "			
$3 \times 1\frac{1}{2}$	$3\frac{1}{4} \times \frac{1}{4}$	24	2	40	2 oz	25	2×1	1	Pint.	$\frac{1}{8}$
$3\frac{1}{2} \times 2$	$3\frac{3}{4} \times \frac{3}{8}$	24	2	40	4 oz.	40	$2 \times 1\frac{1}{2}$	1	,,	$\frac{1}{4}$
6×2	$6\frac{1}{2} \times \frac{1}{2}$	20	2	40	8 oz.	50	2×2	2	,,	$\frac{1}{2}$
$7 \times 2\frac{1}{4}$	$7\frac{1}{2} \times \frac{3}{4}$	18	2	40	12 oz.	60	4×4	3	Quart.	$\frac{3}{4}$
$9 \times 2\frac{1}{2}$	$9\frac{1}{2} \times 1$	18	2	38	1 lb.	100	7×5	6	,,	1
10×4	$10\frac{1}{2} \times 1\frac{1}{8}$	16	2	38	3 lb.	100	9×7	6	,,	2
12×6	$12\frac{1}{2} \times 1\frac{1}{4}$	16	2	36	5 lb.	150	9×7	6	,,	3
14×8	$14\frac{1}{2} \times 1\frac{1}{2}$	14	2	36	12 lb.	200	9×9	8	,,	6

CHAPTER III.

ACCESSORIES TO COILS.

§ 22. A LIST OF ACCESSORIES TO COILS.—A coil made as directed in the preceding chapter, will, when current is supplied to it, work, and give results at the terminals of the secondary wire. There are, however, several accessories which will increase the efficiency of a coil, most of which are necessary to a successful application of the induced current. The accessories to a spark coil are, a condenser to take the extra charge of the core and primary wire, and a discharger to direct the discharge of sparks from the terminals of the secondary coil. The accessories to a medical coil are many, but the most necessary are, a commutator to change the direction of the current in the primary coil, a regulator to regulate the magnetic intensity of the core, a separate rheotome, a pair of conducting cords, a pair of interchangeable handles for the various rheophores, and a set of rheophores or suitably formed conductors for applying the current. To these may be added, a milliampère meter for measuring the strength of the current, and a rheostat or set of resistance coils to regulate its strength.

§ 23. THE CONDENSER OF A COIL.—It may be said that a spark coil is of little use without a good condenser. As the efficiency of these coils depends upon a good condenser being provided to each, I will devote a little attention to detailed instructions for making one. A condenser for a spark coil is made of sheets of tinfoil insulated from each other by sheets of such insulating substances as gutta percha, varnished paper, or paraffined paper. We shall therefore need some sheets of good tinfoil, obtainable from dealers in electrical instruments. I prefer paraffined paper to all other insulating substances, and the paper selected for this purpose should be a tough thin paper of close texture, free from flaws, cracks, and pinholes. In Mr. Bottone's excellent little book on "Electrical Instrument Making for Amateurs," the student is directed to obtain "at any photographic stores some sheets of *plain* paper (not salted or albumenised) known as Papier Rive. These sheets run about 22 in. × 18 in., so that each sheet if cut in half lengthwise, and in three across, will give six sheets 7 in. × 9 in." In Dyer's book on "Intensity Coils," "a moderately thin and not too heavily sized" paper is recommended. Paper nearly resembling bank-note paper is the best. Failing this, the foreign letter or note paper, of good quality, made by the Co-operative Paper Manufacturers at Angoulême, in France (Laroche-Joubert & Co.), will form a good substitute. The selected paper for the condenser must now be cut into sheets two inches longer and wider than the sheets of tinfoil used in the condenser—that is to say, there must be a clear margin of

one inch of paper all around the edges of each sheet of tinfoil. The size of the tinfoil sheets to suit as a condenser for each coil will be seen on referring to the table of dimensions of coils in § 21. We shall need about half-a-dozen more sheets of paper than we have sheets of tinfoil.

Each sheet must be closely examined for pinholes and flaws, by holding it up between the eyes and a strong light, and all defective sheets must be rejected. The selected sheets should then be laid smoothly in a tin baking-dish, or a photographer's shallow white porcelain dish, and some thin shavings of paraffin placed on each leaf. A few lumps of paraffin may now be placed on the top leaf, and the whole put in a slow or moderately heated oven, in which the paraffin will melt and saturate the paper. This will then become semi-transparent throughout, if every part has been thoroughly soaked in the hot wax. The dish should now be taken out of the oven, and each sheet lifted out separately by one end with a pair of forceps, held over the dish to drain off the surplus wax, then laid on a sheet of glass to set hard. If the room is cool, the paper will set hard at once, even whilst passing it from the dish to the glass.

The tinfoil for the condenser should be cut into small sheets, the number of which and the size being given in § 21. Two different methods of building a condenser are adopted, and the sheets should be cut to suit the method selected. In one, the ends of the tinfoil are made to overlap the sheets of paper. In the other,

strips of tinfoil are cut for the purpose of overlapping the ends. If this method is adopted, an equal number of strips of tinfoil, 3 in. × 1 in., must be cut to the number of tinfoil sheets employed. Two pieces of hard wood, such as mahogany or walnut, must now be procured, cut to the size of the paper sheets and smoothly planed down to a thinness of $\frac{1}{8}$ in., then varnished on both sides. Sheets of thin ebonite or vulcanite may be used for the purpose if so desired. In the condensers of cheap coils, the covers are made of thick cardboard. If hardwood cannot be procured, pine or common deal may be employed. These pieces of wood will enclose the paraffined paper and tinfoil between them, as between the covers of a book. Lay one of these covers on a table or bench, then place two sheets of the paraffined paper on it, one overlapping the end of the board 1 in. to the right and the other 1 in. to the left. On the centre of this (so as to leave a margin of 1 in. all around the tinfoil) place a sheet of tinfoil, and on this, to the right, place one of the narrow strips of tinfoil so as to have 2 in. of the strip resting on the sheet, and 1 in. projecting over the end as shown at T in Fig 25. Over this place one sheet of paraffined paper with the edges square with the sheet below, then place another sheet of tinfoil and strip of the same as at first, but projecting at the left or opposite end to the one below, then another sheet of prepared paper, and so on, building up a pile of alternate sheets of paper and tinfoil with strips projecting alternately left and right until the last sheet of tinfoil has been laid. On the top of this last lay two

sheets of prepared paper, one with its end overlapping the pile 1 in. to the left, and the other overlapping the pile 1 in. to the right. When the pile is finished, these overlapping ends will turn down over the ends of the projecting strips of tinfoil on each side. The pile being complete, place the other cover board on the top; on this place a heavy plate of iron, and apply pressure by adding weights or other means, until the whole pile has been pressed down thin and smooth. If an iron plate has been laid on the bench, or the condenser has been enclosed between two iron plates, the pressure may be increased to half a ton, and the efficiency of the pile

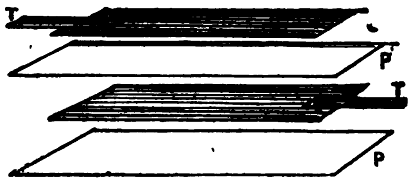


FIG. 25.—How to Build a Condenser.

increased thereby. The whole compressed pile should now be tightly wound with strong tape or with webbing to bind the whole firmly together, as shown at Fig. 26, and the end of the tape stitched to prevent it from unwinding. This done, the projecting strips of foil should now be gathered into a bunch on each side, and soldered to a small piece of sheet brass or copper placed in the middle of the bunch, for convenienee in attaching a connecting binding screw. In the cheap French coils now in the market, a strip of tinfoil is pinched tightly between the overlapping ends of the condenser strips,

and this alone is employed to connect the condenser with the foot of break spring and pillar.

The condenser for a small coil is sometimes made up of long strips of tinfoil, alternating with strips of paraffined paper, in such a manner as to have the sheets of tinfoil overlapping the ends alternately, instead of employing specially cut strips for the purpose.

In building the condenser of a large spark coil, special care must be exercised in the selection of the tinfoil and paper. See that each sheet of paper is quite permeated with paraffin, and ironed smooth afterwards between sheets of blotting paper. Use two sheets of prepared paper to each sheet of tinfoil. There should also be

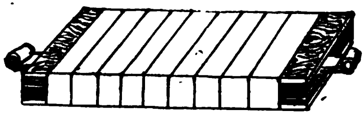


FIG. 26.—Shape of Condenser when finished.

some four or five sheets of paper placed as a foundation for the pile, and an equal number to finish the pile, half of each being allowed to overlap sufficient to cover the ends of the pile when this has been compressed.

Some coilmakers employ sheets of gutta percha tissue as insulators between the tinfoil. This is bad, because it is so liable to crack and be pierced with sparks, as it becomes dry with old age. Some insulate the paper with beeswax, others with a resin composition, and others with shellac varnish made with one ounce of shellac dissolved in six ounces of methylated spirits of wine. Although this last is preferable to some of

the others, I consider all inferior to paraffined paper. If the exact number of tinfoil sheets for the condenser of a coil has not been previously found and stated in a plan of a coil, we must find the number by actual experiment, building up the condenser, sheet by sheet, and trying it with the coil for which it is intended until the best effects have been obtained. This is shown by a small spark at the contact points of the break, and a long spark from the terminals of the secondary coil. When the maximum length of spark has been found, there will be no advantage in adding more sheets of tinfoil. Connection may be made by means of temporary brass clamps until the full number of sheets have been found.

§ 24. USE OF THE CONDENSER.—The condenser, when finished, is placed in a recess made for it in the hollow base of the coil. One end of the condenser is connected by means of a length of silk-covered No. 20 wire with the foot of the break-pillar, and the other end by similar means with the foot of the break spring, as shown at Fig. 13. It would therefore form a loop or branch of the primary circuit.* If the pillar and bracket has been furnished with screwed tangs, nuts, and collars, connection with them can be easily made beneath the coil base, and if the ends of the condenser strips have been soldered to terminal plates of brass or of copper, these can be easily connected, by means of brass binding screws, with the connecting wires. Constructed thus, the condenser can be easily taken out for repairs at any time, and replaced when repaired, without

* If the sheets of tinfoil were not insulated.

recourse being had to the tedious processes of soldering and unsoldering the connections. The condenser should be closely packed with pieces of paper, cotton wool, or other suitable packing, to prevent it from shaking about and receiving injury from being shaken loose.

Some coil-makers employ strips of cork to fill up the space between the sides and ends of the condenser and the sides and ends of the receptacle in which it is placed. Others simply place two pieces of cork on the condenser and screw the bottom board of the condenser box down tight on these, and thus wedge the pack firmly between the top and bottom of the box. The best packing for the purpose is made of thick india-rubber, cut into strips the length of the condenser, and laid along on both sides so as to wedge the pack firmly in the box.

The use of a condenser is as a store for the extra current induced in the primary by its own coils of wire acting on each other, by the magnetism of the core, and by the back inductive influence of the secondary coil. These influences all tend to form an extra current in the primary coil, rushing back in the contrary direction to that of the primary current immediately the circuit is broken. It therefore impedes the flow of the primary current immediately the contact is made again, and the two opposing forces waste their energy by forming sparks at the point of contact between the tip of the contact screw and the speck of platinum on the contact spring. When a properly made condenser of sufficient capacity is used, this

extra current rushes into the condenser and charges it with electricity much as a Leyden jar is charged. When contact is made again, the condenser discharges itself, and the line of discharge is then in the same direction as that of the primary current. As a consequence, the primary current from the battery is assisted by the charge from the condenser, and the influence of this auxiliary is seen in an increased length of spark from the terminals of the secondary coil, and a decreased spark at the contact points of the rheotome.

§ 25. THE DISCHARGER OF A SPARK COIL.—When a small spark coil is about to be built for lighting gas jets, or for illuminating vacuum tubes, it is not necessary to provide a separate piece of apparatus to regulate the discharge of the spark. The two ends of the secondary wire are brought out to two binding posts or connecting screws fixed in the bobbin ends or in the base of the coil, and the connecting wires are led from these to the gas burners or to the connecting studs on the revolving apparatus of the vacuum tubes. But, if a large spark coil is employed for deflagration experiments, and the sparks have to be directed on to or through a substance, we must have some means of directing the discharge, some apparatus with which we can direct the stream of sparks without running the risk of receiving a shock from the coil. This is effected by the use of two metal rods held in ebonite handles or similar insulating substances, and supported on insulated pillars. A pair of such rods, suitably mounted, is named a discharger. An easily constructed discharger

of simple form is shown at Fig. 27. This consists of two insulated pillars made out of two equal lengths of $\frac{5}{8}$ in. glass rod or tube, cemented into a brass foot socket and topped with two brass gas tube joints or T-pieces cemented to the glass. A pair of brass rods made out of brass tube and fitted to slide easily in the horizontal part of the brass T, will serve as discharger holders when furnished with handles made of hard baked wood or of ebonite. The ends of the brass tube should each be plugged with a brass plug terminating in a platinum tipped point. The discharger may be

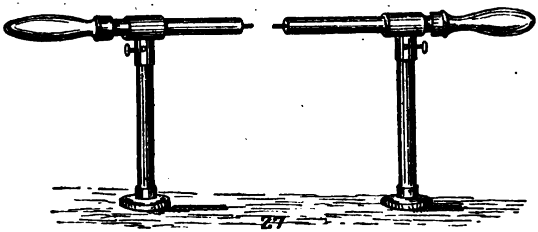


FIG. 27.—Discharger for small Spark Coil.

mounted on a separate base or on the base-board of the coil, the wires from the secondary coil being attached to the T-pieces of the discharger. Such a discharger can only be used in one direction, since the rods are placed opposite each other in a horizontal position. If we wish to deflect the sparks from a horizontal direction, a universal ball and socket joint, or a pivoted joint, should be fitted to the top of each glass pillar, and the discharger rods made to slide in these. A discharger made in this way is a much handier instrument than one having only T-sockets for the rods

to slide in. The rods may also be made of solid wire and more slender than those shown in the figure. (From $\frac{1}{4}$ to $\frac{5}{16}$ in. is quite stout enough.) If a small hole is drilled in the end of each rod, and this is met by another holding a small set screw, the platinum tips may be replaced with pieces of other wire, and thus the character of the discharge from other metals be noted. A similar fine hole may be pierced in each rod near the handles, to hold conductors from the ends of the secondary coil. If every part is well made and fitted, the conductors, of silk-covered wire, may be carried up through hollow glass pillars to the sockets in which the discharger rods slide, and thus all connections be hidden from view. In view of taking exact measurements of the length of spark, it is advisable to grade the discharger rods, and mark them in decimal parts of inches scribed with a fine steel point on the smooth brass rods. A small table made of ebonite or of glass, mounted on a glass pillar placed midway between the two dischargers, will also be a useful acquisition, to hold a tuft of guncotton or any other substance through which we may wish to send the sparks.

§ 26. THE COMMUTATOR OR REVERSER.—This accessory is a useful addition to a medical coil, since it enables the operator to send the current through the primary coil in the opposite direction at will, and reverse it without having to change the battery connections. It is also sometimes used by operators with the spark coil for the same purpose. This accessory is made in several different forms, one of which is shown at Fig. 28;

sketches of the various parts being also given at Figs. 29 to 33.

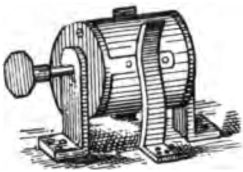


FIG. 28.

Cylindrical Current Reverser or Commutator.

It is composed of a cylinder of ebonite, ivory, hard baked and paraffined wood, or similar insulating substance, fitted with metal ends and mounted on a pair of metal standards connected with the terminal binding posts of the battery. A tongue of metal projects from each end and overlaps the cylinder; against

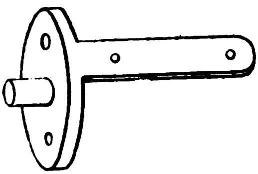


FIG. 30.

FIG. 32.

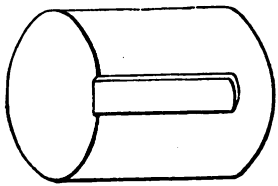


FIG. 29.

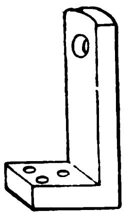


FIG. 31.

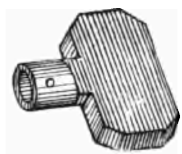


FIG. 33.

FIG. 29.—Ebonite Cylinder of Commutator. FIG. 30.—Brass end-piece of Commutator Cylinder. FIG. 31.—Supporting Bracket of Commutator. FIG. 32.—Conducting Spring of Commutator. FIG. 33.—Brass or Ebonite Thumb-piece.

these press two brass springs, connected with the primary circuit of the coil. A diagram of the arrangement is given at Figs. 34 and 35. The cylinder (Fig. 29) is 1½ in. in

diameter by 1½ in. in length, turned true, and smoothly polished. To the ends of the cylinder must be fitted two discs of brass, each carrying a short brass spindle ¼ in. in diameter, and a projecting tongue of thin brass or of German silver, 1¼ in. in length by ⅜ in. wide, as shown at Fig. 30. The discs will be attached to the ends of the cylinder by short brass screws, and the projecting tongues may be let in nearly flush with the sides of the cylinder on exactly opposite sides, then secured by two short screws in each. Their position to each other is indicated in the diagram (Fig. 34). One of the spindles should be long enough to pass through one of the standards, and be fitted with a milled head or a thumb piece, to turn the cylinder when required. The standards, in which the cylinder works, are merely brass brackets, 1 in. by ½ in. with ⅝ in. feet, shaped as shown at Fig. 31. These may be fastened by screws to the baseboard of the coil in the position shown at C, Fig. 15, with the cylinder mounted between them. On each side of the cylinder two springs of brass, or of German silver, shaped as shown at Fig. 32, must now be fixed, with their points pressing hard against the sides of the cylinder. Beneath one of these springs, one end of the primary wire must be tightly clipped by means of the holding-down screws, whilst the other end of the primary, or the wire from the break pillar, must be attached to the other spring, as shown at Fig. 14. The action of this commutator is more easily explained by reference to the diagrams (Figs. 34 and 35). In these diagrams P represents the position of the

positive pole of the battery, and N the negative pole. That is to say, P will represent the position of a binding post, on the base of the coil, connected to the carbon plate of the battery, and N will represent the position of the opposite binding post connected with the zinc plate of the battery. The current passes from zinc to carbon, from thence to P, then along the course pointed out by the arrows to the bracket and end-piece No. 1. In diagram 34 the current passes by end-piece No. 1 to spring A, then by connecting wire to binding post C,

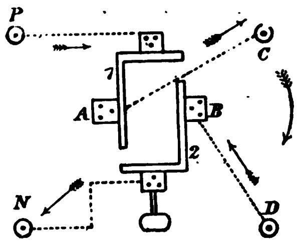


FIG. 34.

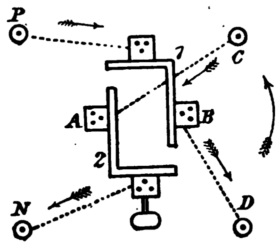


FIG. 35.

Diagram of connections to Commutator.

from this through the primary of the coil in the direction of the curved arrow to D, then to the spring B, and back to N by the end-piece No. 2. Now let us turn the cylinder to the right, so as to throw the connecting bar of end-piece No. 1 against the spring B, and that of No. 2 against the spring A, as shown at Fig. 35. The current will now pass in the opposite direction, from P to B instead of A, from B to D instead of C, then through the coil, back by way of C A and No. 2 to N, instead of D B No. 2. By turning the cylinder so as to have the

springs resting on the cylinder instead of on the contact pieces of metal, the current will be stopped altogether. Thus we can alter the direction of the current, or turn it off from the coil, by a turn of the wrist as required.

A defect in this form of reverser has been pointed out by Mr. A. Caplatzi. When the brass connecting strips are let in flush with the surface of the cylinder, they sometimes fail to make good contact with the springs, because these are weakened by keeping them always at the same tension. It is therefore advisable to have the strips raised at least ⅛ in. above the surface, and to have the springs resting on the cylinder when the coil is not in use. In a commutator made by M. Ruhmkorff, and shown me by Mr. Caplatzi, the cylinder is replaced by two discs of ebonite connected by two brass bars, against which the springs press when contact is made. This hollow drum is a decided improvement on the solid cylinder, because the springs are relieved from tension when the commutator is not in use.

In one form of commutator, two circles of brass are fixed to the edge of an ebonite disc, and metal strips connect these (one above and the other below) with two short pins, one of which fits in a step bearing beneath the disc, and the other in a bracket projecting over it. Springs on each side press against the edge of the disc, as in the form previously described. As the disc is supported vertically, the button for moving it is on top instead of at the side.

In another form of commutator known as the "Brequet Reverser," a double lever switch has its two levers

connected by a bar of ebonite pivoted to both, or by a brass bar connected by insulated pivots. The arrangement is shown in diagram at Fig. 36. The two pivots of the levers P and N are the positive and negative poles of the battery. The two circles, B and C, are the terminals of the primary coil. These are connected by short wires, as shown by the straight lines, with the studs A, D, and K. A short wire, as shown by the curved line, also connects the studs A and K. When the levers of the switch rest on studs A and D, the current will traverse the circuit by the path P A B C D N. But when the ends of the levers rest on studs D and K, the path of the current will be P D C B A K N, or in an opposite direction to that of the first position.

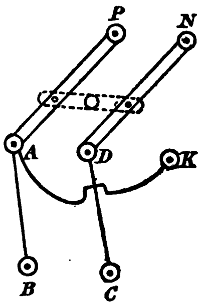


FIG. 36.

Diagram of Brequet Switch Reverser.

There are several other forms of current reversers made, but all work on the same principle of action.

§ 27. REGULATOR FOR MEDICAL COIL.—In applying the induced current of a secondary coil to physiological purposes, it is desirable to have the means at hand for regulating the tension and density of the current. This is specially desirable in employing an induced current for the diagnosis of disease. Although some alterations may be made in this by employing a coil of several powers and a rheostat, or set of resistance coils, a still greater nicety of regulation may be secured by having a regulator for the current in the coil itself.

The density and tension of the induced current from the secondary wire of a medical coil is governed by the magnetic intensity of the iron core within the primary coil. If this is strongly magnetised, the current from the secondary and also the induced current from the primary wire will be correspondingly strong. The regulation of current strength may be secured by several methods. We may employ a stronger or a weaker current to work the coil, by using a battery of more or less cells, or a set of larger cells, the magnetism of the core being stronger or weaker as we increase or decrease the strength of the primary current. If a large battery of several large cells be employed, we may reduce the volume of current passing through the primary, by interposing resistance coils in the primary circuit, or by employing a water regulator. If a plunge battery, with arrangements for raising or lowering the plates gradually at will, be used, the density of the current may be increased by lowering the plates, or decreased by raising them out of the liquid in the cells. If a condenser is attached to the coil, the induced current of the secondary can be greatly increased in tension by throwing the condenser in circuit as in a spark coil. The current may also be regulated by the action of the rheotome or current interrupter, the impulses being most intense when the vibrator has a long spring and works slow, and less intense when the spring is short and vibrates very fast. The tension and density of the induced current is also proportionate (all other arrangements being suitable) to the mass of iron in the core of

the coil. The tension and density of the induced current, up to a certain limit (governed by the size of wire in the primary, the number of turns it takes around the core, and the primary current sent through it), is increased by an increase in the mass of iron in the core, and decreased by this mass, as by shortening the core or lessening its diameter. If, therefore, the core be made movable, or it can be partly withdrawn from the coil, the reduced current can be regulated to a nicety by exposing more or less iron of the core to be magnetised. A movable core for a medical coil is shown at Fig. 37. The core is first made as described in § 10, both ends being consolidated with solder. A brass disc with protruding tang may now be soldered to one end, and a knob of hard wood fitted to this to form the handle. The bundle of iron wires may now be covered neatly with one fold of thin leather (bookbinders' morocco leather) glued to the core, and the edges of the leather hidden by a slip of paper marked in scale with decimal parts of inches, as shown in the figure. If this is used in a vertical coil, a thin spring of German silver should be fixed in the bottom to prevent the core from slipping down when partly withdrawn. No such provision will be needed in a horizontal coil.

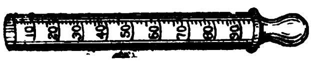


FIG. 37.

Iron Core Regulator for Medical Coil.

A novel method of regulating the tension of the induced current from a medical coil has been introduced by Mr.

Coxeter, 4 and 6, Grafton Street, Gower Street, London, in the manufacture of his portable medical coils. A steel pin, fitted with an ivory head, is made to slide in a groove on one side of the primary coil, and is so arranged as to short circuit few or many of the primary coil turns at will. The tension of the induced current is reduced by thus short circuiting two or more turns of the primary as may be desired. This device does away with the necessity of making the coil in sledge form, or in having either a regulating tube or a movable core. A portable core, thus constructed, is mounted on an ebonite platform over 40 cells of Coxeter's dry battery, and the whole provided with switches by which the direct current from the batteries may be used, or the induced current from the coil, as may be required.

Another form of regulator is shown at Fig. 38, and in section at Fig. 14. This consists of a thin brass tube made to slide in the bobbin of the primary coil over the core. The core is fixed by one end to one of the bobbin ends of the coil, as described in § 10, and the brass tube slides over it, covering it as a sheath, from the other end. The tube of brass, therefore, occupies the thin space between the exterior of the core and the interior of the coil bobbin. It is desirable that both the outside and inside of this tube be made smooth and true to slide easily in the bobbin and over

FIG. 38.
Brass Tube Regulator for Medica Co

the core with little friction, and to take up as little space as possible. The outer end is closed with a brass disc and knob, to serve as a handle in drawing out the tube. When the brass tube is pushed into the bobbin, and covers the entire length of the core, it forms a closed circuit around the core, and absorbs into itself part of the inductive effects of the primary current. The core is, therefore, but feebly magnetised whilst covered with the brass tube, and this is shown by the feeble action of the rheotome when worked by the magnetism of the core. The brass tube also absorbs or screens the lines of magnetic force set up in the core and lessens their inductive influence on the primary coil. It acts as a damper to the current in the coil, and its effects are observable throughout the primary circuit, even altering the beat of the rheotome spring when this is worked by a separate electro-magnet wound with wire connected in circuit with the primary coil. When the tube is withdrawn from the coil, and the wire is left exposed to the full influence of the current, full effects are attainable from the coil. This form of regulator is adopted by the makers of street coils. A piece of thin cat-gut is fixed by one end to the regular tube and is carried over pulleys around a wheel at the back of a dial, then fastened by the other end to a weight working in the pillar supporting the dial. As the regulator tube is drawn out, the cat-gut revolves a wheel which moves a hand on the dial, and the weight draws the cat-gut back when the tube is again pushed in the coil.

Water regulators for coils are merely water rheostats or resistances, placed in the primary circuit to keep back part of the primary current. These are noticed in section 31, p. 102.

Another means of regulating the current is that of making up the coil in a peculiar manner, known as the sledge method of constructing a coil. This form is also noticed in section 39, p. 131.

§ 28. SPECIAL RHEOTOMES OR BREAKS.—The rheotome, or break of a medical coil, is a most important part of the apparatus. On the perfection of its construction and mode of action will depend the efficiency of the instrument as a therapeutic agent. The beat of the rheotome should be regular and rapid. The vibrations of the break-spring and hammer must be very rapid and maintained at an equable speed. Long and slow strokes of the vibrator cause the induced current to be delivered in a series of smart jerks, which are painful and injurious to the patient. It is altogether a popular delusion to suppose that most good is being done to a patient when the effects of the current are most felt in the form of painful sensations. Much harm may be done to a sensitive patient if the rheotome hammer sticks to the core, then starts with a sudden jerk, or the spring makes imperfect contact with the platinum-tipped screw, thus causing irregular action of the break. Care must, therefore, be taken to have the core of the magnet and the head of the hammer made of soft iron well annealed, so as to avoid the retention of magnetism in them after the current is broken.

The spring of the hammer should be of good German silver, adjusted as to stiffness to suit the coil in hand, and sufficiently short to vibrate rapidly. The platinum speck on this spring should be either oblong or rectangular, and the bracket, carrying the contact screw, should have an adjusting arrangement for moving the contact point along the speck, and thus alter the stroke of the vibrator at will. The point of contact should have a surface of not less than $\frac{1}{32}$ inch, or a cross-

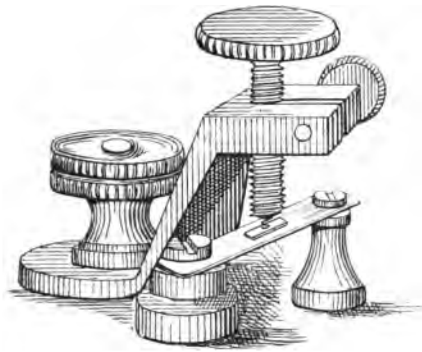


FIG. 39.
Dr. Kidder's Rheotome for Medical Coils.

sectional area equal to that of No. 20 B.W.G. platinum wire. Messrs. Beard and Rockwell, the distinguished American electro-therapeutists, recommend a contact made of a *spiral* of platinum wire soldered to the tip of the contact screw, instead of a rigid point of wire, such as that usually employed in making contact points. A rheotome of this kind, invented by Dr. Jerome Kidder, of New York, is shown at Fig. 39. It is in

tended for the bobbin end, or platform, of a vertical coil. The arm of the bracket is slit and furnished with a set screw to fix the contact screw when it has been adjusted. The bracket can be moved from one side to the other by loosening the double-headed screw at the back, and thus the spiral contact point can be moved to a fresh spot on the break spring. This form can be worked by a separate electro-magnet if thought desirable.

FIG. 44.
Dr. Spamer's Portable Medical Coil.

At Fig. 44 is shown the rheotome employed by Mr. K. Schall, 55, Wigmore Street, London, W., in the construction of his portable medical coils, and Figs. 40 to 43 show the various parts of the same. The small bobbins on the electro-magnet, Fig. 40, are wound with one layer of silk-covered wire, of the same gauge as that used in the primary of the coil. The break spring, Fig. 41, is supported on the top of the pillar, Fig. 42, with the hammer H over the armature A. The adjusting screw and bracket, Fig. 43, is then fixed with the point of the screw bearing on the platinum speck P, and the whole adjusted to suit the current passing through

the coil. This form of separate rheotome is employed on the platform of vertical coils. In the larger horizontal coils of the same maker, the rheotome is fixed on the base of the coil at one end, the electro-magnet being placed in a vertical position on one side, the supporting

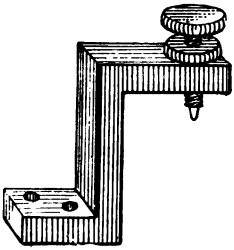


FIG. 43.

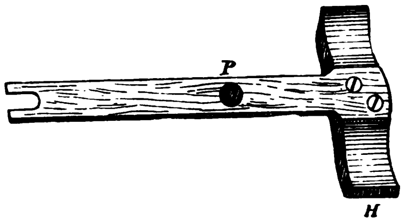


FIG. 41.

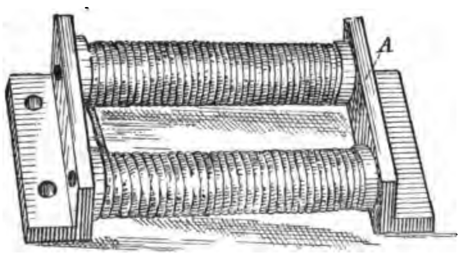


FIG. 40.

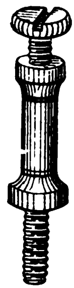


FIG. 42.

FIG. 40.—Magnet and Armature for Horizontal Rheotome. FIG. 41.—Spring and Hammer for Horizontal Rheotome. FIG. 42.—Pillar to hold Spring of Rheotome. FIG. 43.—Bracket and Contact Screw for Horizontal Rheotome.

pillar of the break spring on the other, and the support of the contact spring fixed to the bobbin end of the coil. At Fig. 45 is shown Dr. de Watteville's coil, with an excellent rheotome of this type, in which there are some important additions and modifications. The contact

spring gives place to a lever pivoted in the fork of a supporting pillar. The short end of this lever is furnished with a spiral spring, and also with a vertical rod supporting a small weight. This spring keeps the lever in contact with the contact screw, and the rate of vibra-

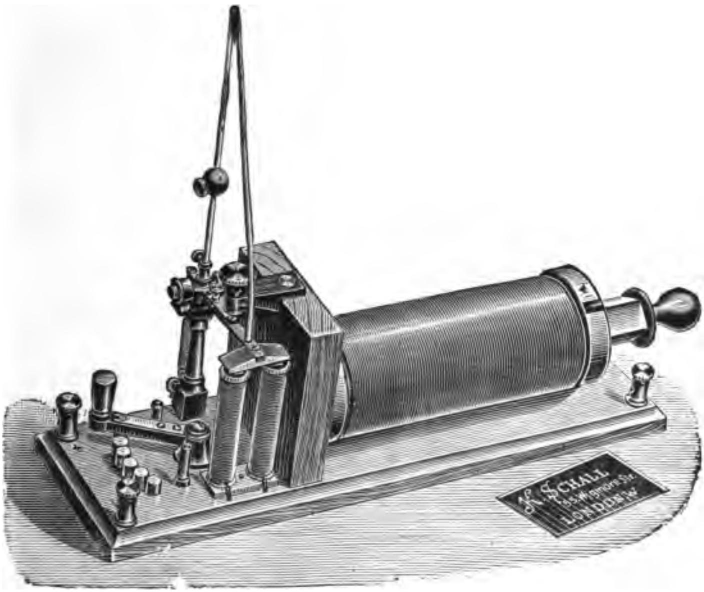


FIG. 45.
Dr. de Watteville's Induction Coil.

tion is controlled by the position of the weight on the vertical rod. In the Dubois-Reymond sledge coil, modified by Professor Lewandowski, contact is made with two platinum-tipped screws instead of one screw, thus giving a more perfect and flexible contact, and also

aiding the action of the commutator about to be described. This instrument has also an improved means of altering the direction of the current, invented by Professor Lewandowski. "This improvement consists of (an appliance named) a disjunctor and commutator, by means of which it is possible to obtain either the usual induced currents in alternating *or in the same direction.*"

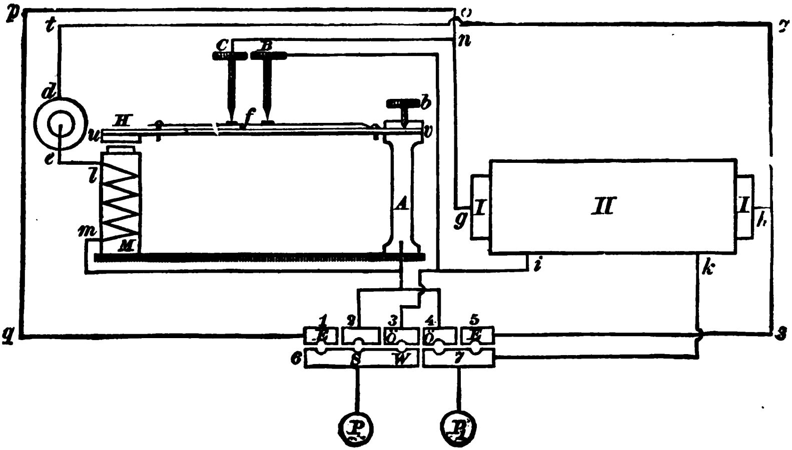


FIG. 46.
Diagram of Connections in Lewandowski's Medical Coil.

The improvement is described in Mr. K. Schall's illustrated price list, by the aid of the accompanying illustration, Fig. 46, which shows the arrangement of the apparatus in diagram form. In this diagram the various parts are shown by the following letters: A, pillar supporting break spring; B C, contact screws; H, hammer; M, electro-magnet; I, primary coil; II, secondary coil;

E O S W, 1, 2, 3, 4, 5, 6, 7, the several parts of the disjunctor, consisting of pieces of thick brass fixed in the base, and placed near to each other, and furnished with holes in which are fitted the connecting plugs of brass. Each piece of the disjunctor is connected to a separate wire, as shown by the lines lettered by italics on the diagram. Following these, we may trace the action of this part." If the commutator (or disjunctor) is plugged at W, alternating currents are obtained from the terminals P and P1 (because then the current is obtained from the secondary coil by the paths ö 3 *i k* 7), if at S, only those currents pass the human body which are induced in the secondary coil by *making* the primary current. (The path in this arrangement is by 2, through A, to the break spring, and contact screw B, from this to *i k* 7.) By plugging the holes O E and O E, only those currents pass which are induced in the secondary coil by *breaking* the primary circuit. By plugging E and E, *extra currents only* are sent. The last three are *not alternating* currents, but flow *in the same direction*, and their strength may be measured by means of an ordinary milliampère meter. Moreover, all the "shocks," or short currents, of which they are composed, are of equal intensity and duration.

§ 29. RHEOTOMES FOR LARGE SPARK COILS.—Some difficulty is experienced in making a suitable contact breaker for large coils, owing to the heating effects of a large volume of current on the high resistance of the platinum contact points, a larger volume of current being necessary to work large coils than that employed in working small ones. Broad and well fitted platinum

contact pieces must be provided for the breaks of large coils, whether the break is worked from the core or by a separate magnet.* The condenser must also be arranged to minimise the spark at the break as much as possible.

But, even when the greatest care has been exercised in making the two contact surfaces true with each other, it is not always possible to prevent for long the destructive action of the disruptive charge of sparks on the platinum. Sooner or later these sparks render the contact surface uneven, and then the sparking evil is intensified, because the resistance of the primary circuit is increased at these points.

This has led to the invention of the mercury rheotome, or contact breaker.

This form of rheotome consists essentially of an ordinary electro-magnet working an armature fixed to the end of a lever placed in connection with the circuit actuating the electro-magnet. One end of the lever is furnished with a fork, which dips into a cup containing mercury and connected with the primary circuit of the coil. When the circuit of the coil is closed, the electro-magnet of the rheotome pulls the armature toward itself, and this draws the fork at the opposite end of the lever out of the mercury and breaks the circuit. This done, the fork falls again into the cup and closes the circuit, and is again withdrawn by the magnet. This action of "make and break" goes on regularly, as in an ordinary contact breaker. Several different forms

* Platinum contacts of $\frac{1}{2}$ in. in diameter and $\frac{3}{8}$ in. in thickness are sometimes employed in the rheotomes of large spark coils.

of this rheotome have been employed by coil makers. In one form, a brass arm, from 4 in. to 5 in. in length, by $\frac{1}{4}$ in. in diameter, has an iron armature 2 in. by $\frac{1}{2}$ in. by $\frac{3}{8}$ in. fitted to one end, and a fork of $\frac{1}{4}$ in. copper rod tipped with $\frac{1}{2}$ in. of an equal diameter of platinum, at the other end. This rod is balanced in the centre in a forked pillar, so as to have the armature over the two poles of a horse-shoe electro-magnet, and the platinum-tipped forks dipping into two glass cups containing mercury. The electro-magnet is worked by one or two cells of a separate battery, the circuit being made and broken by an ordinary contact spring placed on the pillar supporting the arm of the armature. The mercury in each cup is connected, one with the terminal binding post on the coil base, and the other with one end of the primary coil. As the brass arm moves up and down under the influence of the magnetic break, the forks at the other end make and break the circuit of the primary coil. A light spring pressing on the arm keeps the fork in the mercury when it is not drawn out by the electro-magnet at the other end, and this spring is adjusted by a screw to regulate the speed of the arm. This form may be modified in the following manner. Only one mercury cup and one contact point may be employed, the primary current being conveyed into the mercury through the platinum-tipped point, through the arm, and through the supporting pillar to the end of the primary coil. The mercury contact may also be used as the break for the actuating electro-magnet, by dipping into it a wire from the battery and

connecting one end of the electro-magnet coil to the foot of the supporting pillar. When thus constructed, the "make and break" will be at the same rate in both circuits, and both be controlled by the adjustable spring on the brass arm. Both of these forms need either a separate battery to work the rheotome, or a separate circuit from a part of the battery employed to work the coil.

In another form, the core of the coil is made to work the arm of the rheotome, an armature being fixed to the arm over the end of the core, all other arrangements being the same as in the form previously mentioned. By employing a two-pronged fork and two mercury cups (the fork acting as a bridge between the two cups), the tension of the current is divided between the two points of contact, and a better contact is insured. But, in this form, every part must be accurately fitted, to prevent undue friction and sticking of the break. As mercury corrodes and eats into brass, copper, and nearly all other metals except iron, the cups should either be made of cast iron or of glass enclosed in a brass case, the latter being preferable. The cups must be insulated from each other and from the pillar supporting the brass arm. The connecting wires must also be insulated from the metal case enclosing the cups, and this should be fitted with a close-fitting cover to exclude the dust and prevent the contents of the cups from being spilt by spirting or splashing. The rods of the fork must pass through a hole in this cover, much the same as the piston rod of a steam engine passes through the cover of its cylinder.

When using the mercury rheotome with very large coils, a considerable volume of sparks pass into the mercury every time contact is broken. These sparks rapidly oxidise the mercury, and thus destroy its conductivity. To prevent this oxidation, Foucalt, the inventor of this rheotome, covered the surface of the mercury with absolute alcohol, and mixed finely divided platinum with the mercury to form an amalgam of the two metals. If the layer of alcohol is very thin, it will be inflamed by the sparks and explode, therefore the surface of the mercury should be covered with alcohol to the depth of an inch or more. In the mercury rheotome of the famous Polytechnic Institution coil, constructed by Mr. Apps, 433, Strand, London, the mercury and platinum amalgam was held in a large glass bottle, and covered with one pint of alcohol. Flashes of light were seen to play on the surface of the amalgam, but the alcohol did not spirt, inflame, or explode.

The mercury break may be worked by hand, if so desired, and thus the working speed of the coil be controlled. Or it may be worked by an eccentric lever, actuated by a vacuum tube motor.

Mr. A. Apps, the well-known maker of large induction coils, has devoted much attention to rheotomes for large spark coils. An improved contact breaker made by him for spark coils has been described and illustrated in the *Electrician* of August 21st, 1891, by Dr. J. A. Fleming, and is reproduced here. (Fig. 47.) On reference to this figure it will be seen that the spring S,

carrying the hammer-head H, has a hole drilled through its lower end, and a peculiar shaped brass collar is fitted in this hole, through which passes the shank of the regulating screw N. The contact pillar A has also a hole drilled through its lower end for the shank of the screw, and this hole is bushed at *m* with a collar of ebonite or similar insulating material. By means of this regulating screw, the platinum contacts C C can be adjusted and the rate of vibration of the spring increased or diminished. Mr. Apps has also devised a form of multiple contact break, which renders it possible to divide the break spark between several points. Mr. Bottone employs a double spring contact break, which reduces materially the length of spark at the rheotome.

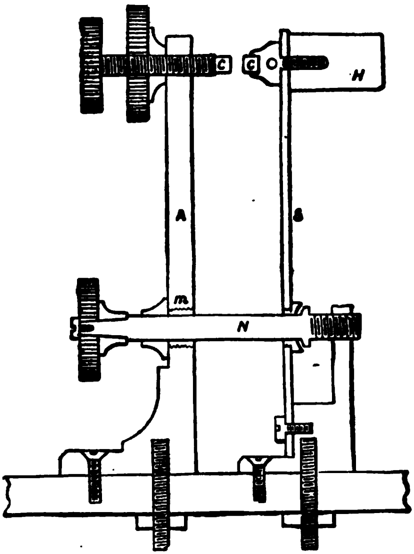


FIG. 47.
Mr. Apps' Improved Contact Breaker for Large Coils.

The rotary rheotomes, attached to some old forms of spark coils, demand a notice in passing, some of these being in use at the present time. These were made in

several forms, but the principle of action was the same in all. One or two strong springs pressing on a toothed wheel completed the primary circuit, which was broken by the intervals between the teeth every time the wheel was moved. By controlling the speed of the toothed wheel, and by alteration in the form and distance of the teeth, the intervals of make and break could be controlled to a nicety. Old medical coils were fitted with similar rheotomes, actuated by winch handles, and sometimes driven at a high rate of speed by band wheels and pulleys. The rasping sensations experienced from coils controlled by such rheotomes, can only be imagined by comparing them with those given by the current from a badly made magneto-electric machine.

§ 30. RHEOPHORES FOR MEDICAL COILS.—These accessories to medical coils are necessary to the application of the induced current to physiological purposes. The name is derived from two Greek words, *rheos*, "a current," and *phoreo*, "I bear along." The name is applied to all the conducting cords and instruments employed in conveying the current from the coil to the patient. The conducting wires from the coil must be flexible. They are therefore made in the form of wire cords and braids, covered with an insulating medium of cotton, worsted, or silk. These cords and braids are made (and sold by professional makers of such material) with the so-called gold and silver threads employed in the gold and silver lace industry. The ends of the braid or cord are clasped in metallic contact with brass tags to fit in the holes of the binding posts and other connectors.

The various rheophores employed by electro-therapeutists are many, and are adapted to special purposes. Their general form is that of an insulating handle of ebonite, ivory, or hard wood, holding a brass, German silver, or silver instrument for the application of the current. As it is not my intention to show how electricity can be employed for the cure or relief of disease and pain, I shall merely give a few illustrations of the common forms of rheophores, and beg my readers to refer to books on the treatment of disease by electricity, for instruction in the use of these instruments. A list of useful books on this subject is published in the excellent illustrated price-list of electro-medical apparatus issued by Mr. K. Schall, 55, Wigmore Street, London, W.

The most common form of rheophore is that known as the "sponge-holder," which consists of a brass tube mounted on a handle of ebonite or other insulating material, and furnished with a metal cup or similar arrangement for clasping a sponge, as shown at No. 12 in the group of figures annexed. The insulating handles should not be large and unwieldy, but of sufficient size to be easily grasped by the hand, and of a shape suitable to the work to be done. Connection with the battery should be made by means of a hole and a small screw in the ferrule of the handle or in the metal conductor, not by means of a rod running through the handle and a screw in the end of it. The sponge-holder or cup should be made to unscrew from the handle, in order that it may be cleansed and set aside clean when

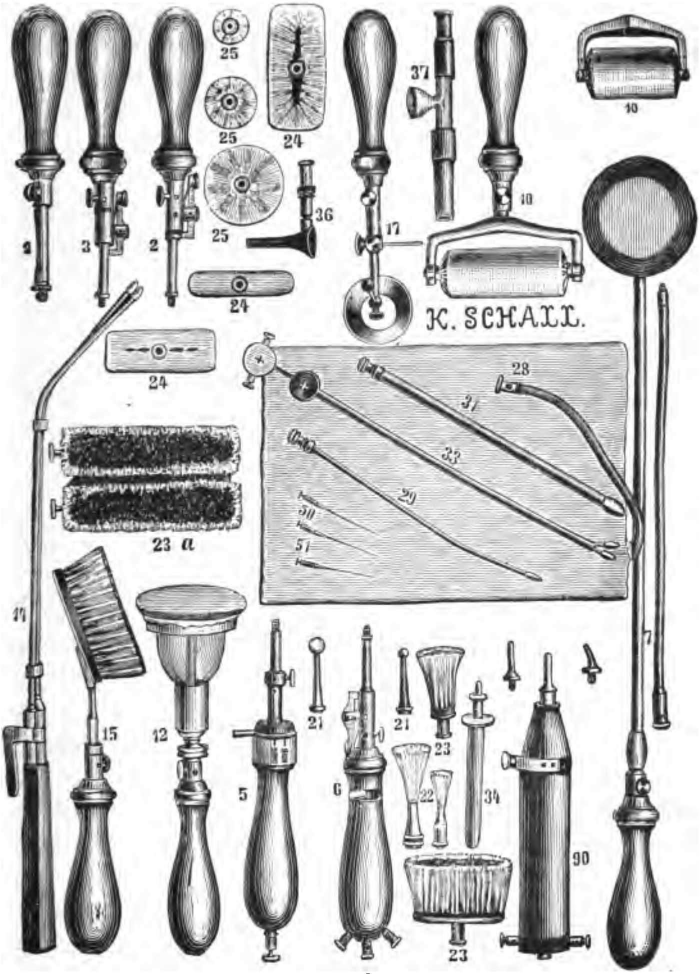


FIG. 48.

A collection of Rheophores, or Instruments employed in the application of Electricity to Medical and Surgical Purposes.

not in use. It should also be made to clasp the sponge or leather pad firmly when in use, but to allow of their easy removal for change and cleansing purposes. This provision should always be made for the removal or interchange of electrodes employed in rheophores.

The ordinary form of insulating handle for rheophores is shown at 1 (Fig. 48). These handles can be fitted with an arrangement for applying the current when all is ready, as shown at 2 (Fig. 48), or a similar arrangement for switching it off when not required, as shown at 3 (Fig. 48). Mr. K. Schall also furnishes handles with an arrangement for reversing the direction of the current, as shown at 6 (Fig. 48), and one with a rheostat combined, having a resistance of 1,000 ohms in 10 subdivisions, as shown at 5 (Fig. 48). The other instruments shown in this group are all used in the various applications of electricity to curative purposes.

§ 31. RHEOSTATS FOR COILS.—This name, derived from two Greek words, *rheos*, "a current," and *statos*, "that stands," is given to instruments employed in switching a definite resistance into the circuit, such as a resistance coil or a water regulator. These control the volume of current by reducing the conductivity of the circuit into which they are brought, and therefore act as check valves in reducing the area of the conductor through which the current has to pass. In the usual form of rheostat, a wire having a high resistance is employed to reduce the current volume. This, for convenience in construction and use, is made in the form of a coil, and wound on a bobbin. The wires are usually

made of such alloys as German silver and "platinoid," because these are inferior conductors to pure metals. Each coil is made of a size and length of wire known to have a definite resistance, and a number of such coils are formed into groups, with each individual coil of the group placed in convenient proximity to its neighbours for easy connection. In one arrangement the coils are fixed to the under side of a board, and the ends of the coils are attached to blocks of brass fixed on the opposite side. These blocks are fixed close to each other, but not touching in any part. Conical holes are bored in the joints between the blocks, so that one-half of each hole is in each block, and these holes are fitted to a nicety with plugs of brass, furnished with thumb-piece heads of ebonite, or with cross-pieces of brass to form heads. The whole group of coils, or any number of them, can therefore be connected together by arranging these plugs, the full resistance of the group being thrown into the circuit when the plugs are all left out. The coils are usually grouped decimally to represent decimal parts of 10, 100, 1,000, or 10,000 ohms, or decimal parts of an ohm divided into tenths, hundredths, or thousandths, as may be desired. The ohm is the unit of resistance universally employed. In some forms of rheostat, blocks of carbon of varying resistance are employed instead of coils of metal. A plug rheostat is shown at Fig. 53, p. 107.

For medical purposes, the set of coils should be arranged in a circle, and connection be made with them by means of a movable switch arranged as a crank, as

shown at Fig. 49. The resistances can then be thrown in gradually, and altered without delay.

Alterations in the strength of the current, when employed for medical purposes, should be effected without interruption. This cannot be conveniently done with plug and similar rheostats, but can be effected by means of a water rheostat. It is well known that ordinary drinking water offers a great resistance to the passage of an electric current, and this property is utilised in the construction of a rheostat. The most simple form of this instrument is that of a glass tube (as that of a glass syringe) made water-tight at both ends with cork plugs containing a piece of platinum wire in each plug. At one end (answering to the piston end of the syringe) the wire is free to move in the plug, and is long enough to touch the wire at the other end of the tube. When the tube is filled with water, and the wires are connected in circuit with the battery and instrument, the resistance of the circuit is increased or lowered by altering the distance of the wires from each other, and interposing a more or less volume of water between their points.

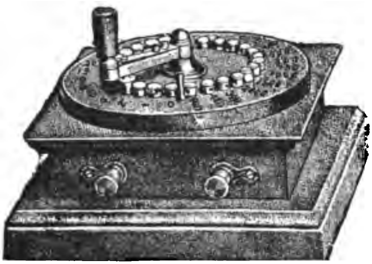


FIG. 49.
Carbon Rheostat with Switch.

At Fig. 51 is shown a hydro-rheostat made and sold by Messrs. Gent & Co., Braunstone Gate, Leicester. This consists of a glass tube having a metal cap at

each end, the cap of one end being provided with a sliding metal rod of sufficient length to reach the bottom of the tube and touch the cap at the other end. When the rod is in place, the two ends are connected, and the current encounters no resistance. When the rod is drawn up and water interposed between the ends, the resistance is increased and the strength of the

FIG. 51.
Water Regulator of Resistance.

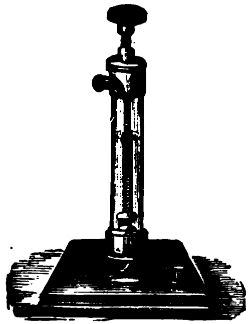


FIG. 50.
Hydro-Rheostat with Screw Adjustment.

current at the electrodes decreased, according to the length of the column of water through which the current has to pass." This instrument is simply placed in circuit by connecting the wires from battery and coil to the binding screws on the base of the instrument. In this form a double set of binding screws are provided to admit of the current being divided between the electrodes and the column of water, if so desired.

At Fig. 50 is shown a form made and sold by Messrs.

King, Mendham & Co., Narrow Wine Street, Bristol. In this form the distance between the two terminals is regulated by means of a screw, and thus a great nicety of regulation is secured.

At Fig. 52 is shown a liquid rheostat, supplied by

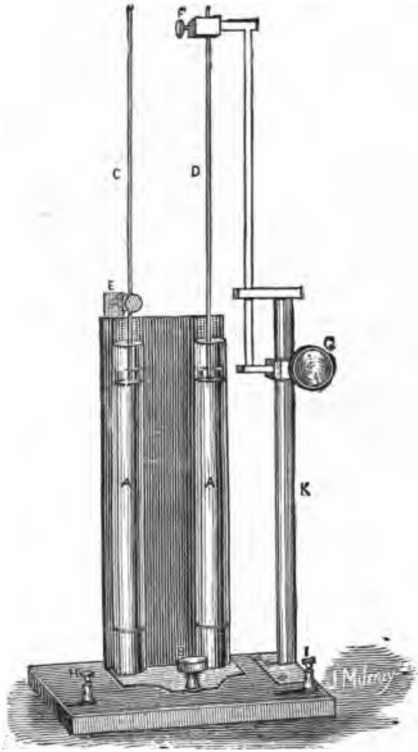


FIG. 52.
Dr. Milne Murray's Liquid Rheostat.

Mr. K. Schall 55, Wigmore Street, London, W. In

this form two tubes and two sliding rods are employed. When both rods touch the metal plate at the bottoms of the tubes, there is practically no resistance. The resistance can be greatly increased by using both sliding rods, and can be nicely regulated by the adjusting screws at the sides of the instrument.

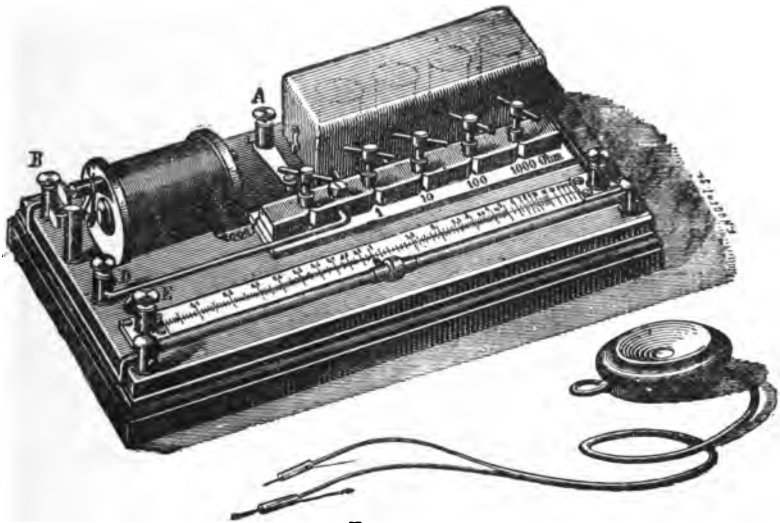


FIG. 53.
Bridge, Rheostat, and Coil.

When a coil is used for physiological experiments, and accurate measurements of the resistance are desired, it is necessary to employ rheostats of high accuracy in connection with delicate measuring instruments and a Wheatstone bridge for nicely adjusting and balancing the resistance. Such an arrangement is shown at Figs. 53 and 54, in an instrument supplied by Mr. K. Schall.

Reference to Fig. 53 will show how this arrangement may be used with a telephone. In this diagram, letters A and B show the position of the battery binding posts; C, the coil; D and E, the binding posts for the conductors to the circuit being measured, as represented by R; F, the binding post to which the bridge resistance, the plug resistances, and one of the galvanometer circuit

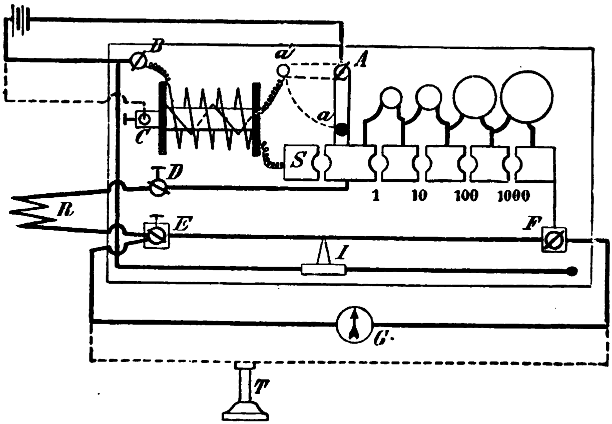


FIG. 54.
Diagram of Connections in Fig. 53.

wires are connected; G, the galvanometer; I, the movable pointer of the bridge; and T, the telephone. The dotted line from *a* to *a*¹ shows the sweep of the switch arm, and S the position of one of the plugs. When the resistance of R has to be determined, the terminals A and B are connected with the battery, and the terminals D and E with the body the resistance of which is to be measured, the wires from G being connected to the

posts E and F, and the switch A resting on *a*. The plugs should now be withdrawn one at a time, and the pointer of the bridge moved until enough resistance has been thrown into the circuit to balance that of R. If the telephone T has to be used, the switch must rest on *a*, and the opening S must be plugged.

§ 32. ELECTRICAL MEASURING INSTRUMENTS.—This term embraces a large class of instruments, ranging from mere current indicators up to delicately-constructed voltmeters and ammeters calibrated to give readings of greatest accuracy. Mere current indicators or galvanometers may be constructed by amateur electricians, but instruments demanding any degree of accuracy in their readings must be left in the hands of skilled electricians. The standard units of electrical measurement are the ohm, volt, ampère, and watt. To these are sometimes added the dyne, erg, coulomb, joule, farad, and gramme-calorie. If we except the joule, which is sometimes used in ascertaining the temperature of electro-cauteries, and the farad, which is used to express the capacity for charge of a condenser, none of these last need be considered here. The *ohm* is the unit of resistance to electric currents, and is approximately equal to the resistance of 129 yards of pure copper wire $\frac{1}{16}$ in. in diameter, or to 106 centimetres of mercury one square millimetre in section. The *volt* is the unit of measurement for the difference of potential between any two parts of an electrical circuit, or the electromotive force of an electric current, and is represented approximately by the electro-motive force of one

Daniell cell. Actually, it is represented by 0·95 of the electro-motive force of the copper-zinc pair in one such cell. The *ampère* is the unit of measurement for current volume, and represents the quantity of electricity produced by an electro-motive force of one volt through a resistance of one ohm. The *farad* is the measure of the capacity of a condenser to receive a charge of electricity, and is represented by a charge of one ampère at a potential of one volt delivered in one second of time. This charge is named one *coulomb*. As measurements are frequently taken of currents much larger and also much smaller than can be expressed by the above-named units, it is usual to multiply or divide the units many thousand or many million times, and give a name to each of these fractions. Thus, the prefix *mega* has been adopted to represent one millionth times, and *micro* one millionth part of a unit. The prefix *milli* has also been employed to represent one thousandth part. The *megohm* is, therefore, a resistance of one million ohms, and the *milliampère* a quantity of electricity representing one millionth part of an ampère. A *microfarad* is the one millionth part of a farad, and is represented in a condenser by about 3,600 square inches of tinfoil. The two last fractions of units are much used in the working of coils, the volume of current from them being very small, thin, or attenuated, and better expressed in milliampères than in the larger units.

§ 33. THE GALVANOMETER.—This name is frequently used to designate any instrument made for the purpose of indicating the existence of an electric current. The

name is fitly given to a measure of galvanic electricity. It is usually applied to current indicators or detectors, such as those shown at Figs. 55, 56, and 57. If the instrument is merely required to test a wire circuit for the presence of an electric current, or to test the condition of a battery, the ordinary linesman's galvanometer, shown at Figs. 55 and 56, will serve the purpose very well. The construction of this instrument is similar

FIG. 55.
Linesman's Galvanometer in Metal Case.

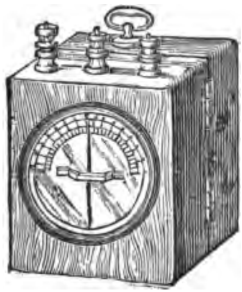


FIG. 56.
Linesman's Vertical Galvanometer in Wood Case.

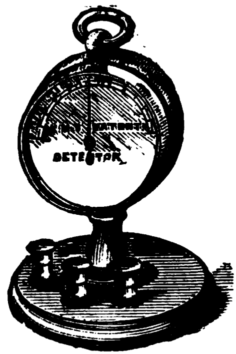


FIG. 57.
Vertical Current Detector.

to that of a single-needle telegraph instrument. A magnetised piece of steel, $1\frac{1}{4} \times \frac{1}{4} \times \frac{1}{16}$ in., is mounted on a steel spindle in a hollow flat bobbin wound with fine wire. The spindle is nicely centered in brass bearings on both sides of the bobbin, and the magnetised steel hangs in a vertical position when at rest in the bobbin, both ends being free to move in the arc of a circle. When a current of electricity is sent through the wire wound on the bobbin, it induces the magnetised steel to

place itself out of its vertical position across the path of the current. The deviation of this needle from a vertical position is proportioned to the strength of the current sent through the wire on the bobbin. The spindle of the magnetised needle is extended to pass through the graduated dial in the front of the instrument, and this end bears a light double-pointed steel needle fixed parallel with the magnetised needle inside the bobbin. The movements of the interior needle are therefore indicated by those of the outside needle on the dial, which is graduated in degrees of a circle. The dial may be of brass or of cardboard. The case may be of wood or of brass, and may be square or round, as taste may dictate. If the bobbin is wound with many turns of fine wire, say of silk-covered No. 36 copper wire, the instrument will indicate small currents of electricity; but if coarse wire (say No. 20) is wound on the bobbin in only a few turns, it will take a large volume of electricity, say from 5 to 10 ampères, to move the needle. In the higher-priced galvanometers, the bobbin is wound with coarse wire for large volumes of current, and over this is wound several layers of a finer wire for more delicate indications. It must be understood, however, that these instruments will not measure the actual current strength of a battery, and are only useful as rough indicators where portability and rapid work is desired, as in testing a battery to see whether it is in working order or not.

For more delicate observations on the movements of small currents, as those mentioned in § 5, we shall require a galvanometer of the horizontal form, such as

that shown at Fig. 58. This consists of a magnetised needle, such as a compass needle, nicely poised and balanced on the point of a steel needle protruding through the centre of a dial. The needle is free to move over a graduated circle on this dial, and, when at rest, will point due north and south, being controlled by the earth's magnetism. Beneath the dial is a coil of very many turns of very fine wire wound on a thin flat bobbin, the ends of the wire being brought out to the binding screws on the base of the instrument. When only a faint current is sent through the fine wire, it has an inductive influence on the magnetised needle suspended above the coil, and causes the needle to place itself across the path of the current, the magnetism of the coil being stronger than the directive magnetism of the earth. The sensitiveness of the instrument is increased by having many turns of fine wire, because each turn increases the induced magnetism of the coil, and a fine wire will only carry a thin current of small volume. The coil is covered with a brass case having a glass top, to exclude dust. The base is of polished hard wood. Both of these instruments are constructed on the same lines as the more expensive and accurate instruments about to be described under the heads of ammeter, milliampère meter, and voltmeter. In the horizontal form of these instruments, the magnetising influence of their coils has to overcome the directive force of the

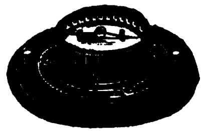


FIG. 58.
Horizontal Galvanometer.

earth's magnetism. In the vertical form, the force of gravity has to be overcome by the magnetising influence of the current passing through the coil. The horizontal form is the more sensitive, but the vertical form gives more constant readings, because its needle is not subject to the variations of the earth's magnetism. Both forms of the ordinary galvanometer are, however, useless as actual measures of current strength. The deviations of their needles will indicate the existence of a current and its direction. The angles of their deflection will also roughly indicate the relative strength of currents made to pass through their coils, but these vary in each instrument, no two galvanometers giving the same deflection. The deflections of the galvanometer needle are governed by the thickness, length, and number of turns of wire wound on its coil, and also by the magnetic condition of its needle. The angle of deflection does not increase in proportion to the strength of the current, and no calculation can be made to convert the readings of the needle in degrees to absolute units of measurement in all galvanometers. This uncertainty has led to the invention of another class of current indicators known as ammeters, milliampère meters, and voltmeters which are constructed to give absolute measurements.

§ 34. AMMETERS.—Ammeters are galvanometers constructed to give direct readings on their dials in ampère units. Various forms of these instruments are in use. In some the principles of construction are the same as in the ordinary galvanometer, a magnetised steel needle being actuated by the strength of the current passing

through a coil. As small magnets are liable to loss of magnetism and consequent fluctuation in magnetic strength, Messrs. Ayrton and Perry have constructed an ammeter in which a strong and constant magnetic field is provided for the needle, in the shape of a strong horse-shoe permanent magnet, with its legs on both sides of the coil enclosing the magnetised needle. In some forms of ammeter, the permanent magnetised needle is superseded by an iron pendulum suspended between the two legs of an electro-magnet. In others an iron core is drawn into an open coil of wire, or solenoid, by the strength of the current passing through the coil. In all forms of this instrument the readings are taken from a pointer moving over a graduated dial. The graduations are in ampères, and the markings are fixed by a careful process of calibration, compared with actual readings on a standard instrument. These graduations or markings are liable to errors arising from the variation in magnetic strength of the needle, and also the variation in the magnetic influence of terrestrial magnetism, when magnetised needles are employed in the construction of these instruments. They are rarely used with induction coils, the currents obtained from these being measured in fractions of ampères by a milliampère meter.

§ 35. MILLIAMPERE METERS.—These instruments, as the name implies, are measures of electric current strength, in milliampères. They differ but very little from ammeters, but are of more delicate construction, and are calibrated with great nicety. Like galvanometers, they are made in various forms, but may be

divided into two classes, the horizontal and the vertical. The horizontal form is made similar to the horizontal galvanometer already described, and is, like it, liable to variation from the variable force of terrestrial magnetism, which is not the same all over the earth. These instruments have therefore to be calibrated to the magnetic meridian of the locality in which they are to be worked, and their readings can only be regarded as

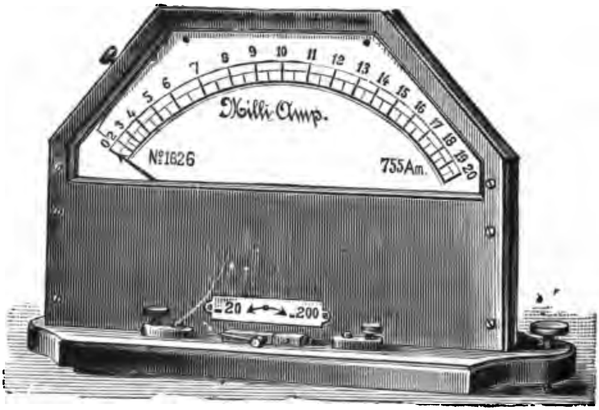


FIG. 59.
Mr. Schall's Vertical Milliampère Meter.

correct for that locality alone. The vertical form is not subject to these variations, but is also liable to errors from alteration in the magnetism of the needle when a magnetised steel needle is employed. Mr. K. Schall supplies vertical instruments without permanent magnets. He claims for these instruments that they are accurately divided, and the divisions are permanently correct whilst the instruments receive fair usage. They

allow of the alternating currents of induction coils being accurately measured, and are graduated to register currents from 20 up to 200 milliampères whether used for galvanization, faradization, or electrolysis. An instrument of this class of galvanometer, made by Mr. Schall, is shown at Fig. 59, and another by Messrs. King, Mendham and Co., at Fig. 60. Among milliampère meters of the horizontal form may be mentioned Gaiffe's galvanometer, shown at Fig. 61. The following description of this instrument is taken from Messrs. T. Gent and Co.'s illustrated list of electro-medical apparatus:

FIG. 60.

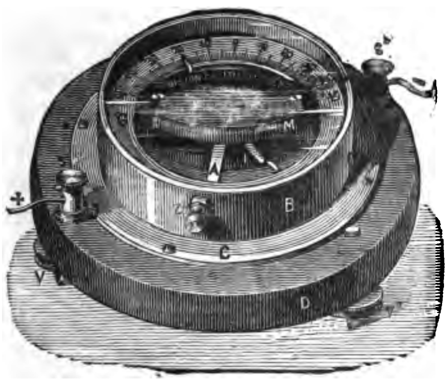


FIG. 61.
Gaiffe's Milliampère Meter.

"This is a milliampère meter of the horizontal form. D is the base upon which the instrument is fixed, V being levelling screws to the same. B is the containing case of metal (with a glass cover) fitting into and free to move

round within the ring C, which is also fastened to the base. The coil is placed underneath the ebonite cover M, the two ends terminating at the binding screw X—S. L is the magnetised needle working upon a ruby centre, the end moving over the scale C. H is an arm of brass, with a forked end passing under the needle, the other end having a terminal screw for preventing undue oscillation of the needle and fixing it in any desired position."

Dr. Edelmann's horizontal galvanometer is also shown at Fig. 62. This instrument has a magnetised needle suspended from a cocoon fibre. The oscillations of the needle are within a copper block which acts as a damper, and prevents excessive vibration, and the works are contained in a polished brass case. In the "pocket" form of this instrument the greatest error is guaranteed to not exceed 5 per cent., whilst in the larger or universal galvanometer of Dr. Edelmann, the error is guaranteed to not exceed 0·5 per cent. These instruments are therefore used when measurements of absolute accuracy are desired. They are made and sold by Mr. K. Schall, 55, Wigmore Street, London, and Messrs. J. Gent and Co., Braunstone Gate, Leicester. The prices range from £2 15s. up to £10.

FIG. 62.
Dr. Edelmann's Horizontal Galvanometer.

Mr. Schall recommends the horizontal form of galvanometer for exact measurements. In his book on

Electro-Medical Apparatus, p. 111, he says: "In the case of *horizontal* galvanometers the deflections depend upon the strength of the current, the intensity of the local terrestrial magnetism where the galvanometer is used, and the inertia of the needle—which has to be overcome, but *not upon the degree of magnetisation of the needle itself*. It can easily be shown that, though a piece of magnetised steel which has lost part of the magnetism it had during the time the division of the instrument in milliampères was made, ought by a current of the same strength to be deflected further from the magnetic meridian than it did at the time of the division—yet, on the other hand, this weaker magnet will also be less influenced by the same current strength. The two conflicting forces (namely, the directive force of terrestrial magnetism and the deflecting influence of the galvanic current) upon the joint action of which the angle of deflection depends, each act upon the needle proportionally to the intensity of its magnetism, and thus the angle of deflection by the law of resultant forces remains the same whatever variations in the magnetisation of the steel may occur. The inertia of the needle is slightest in the case of instruments the magnet of which is suspended on a cocoon fibre, as in this case the friction also remains always the same. Such instruments have therefore the very great advantage of having their graduation correct for a certain locality, and this graduation will always *remain* correct and reliable." As the intensity of the earth's magnetism varies a little during the year, and increases slightly year by year

this statement respecting the absolute accuracy of the graduations is not literally correct. Mr. Schall values this variation at ·04 in ten years, or a possible error in the graduations of 2 per cent. during that time.

CHAPTER IV.

SPECIAL FORMS OF INDUCTION COILS.

§ 36. LARGE INTENSITY OR SPARK COILS.—Small intensity or spark coils may be said to include those giving sparks in air from $\frac{1}{8}$ inch up to 3 inches. From this upwards, that is to say, those coils giving sparks in air from 3 inches upward, may be classed as large spark coils. Small spark coils may be constructed with only one continuous coil of fine wire to form the secondary coil, but the secondary coil of large spark coils should be built up in divisions. This plan has been found advisable in building coils to give a 1 inch spark, to prevent possible sparking through the turns of wire at the ends of the layers of secondary wire. The electrical pressure or tension of the induced current at the terminals of the secondary wire in a coil to give only a 1 inch spark in air, ranges between 50,000 and 60,000 volts. If this spark can pass from terminal to terminal through the bad conducting medium of air, how much more readily will it pass through the turns of insulated wire containing a good conducting medium in the form of

copper, which intervene between the first turn of the secondary and its last turn, or vertically between the terminal end and the commencement of the coil? As these two points are the most vulnerable parts of the coil internally, because of the enormous tension, potent tial, or stress of the induced current at these two points, it is advisable to place them far apart, and this can only be done by dividing the secondary coil into two or more parts. As the current at the commencing end and the finishing end of each of these divisions has not such a high potential as that of the current at both ends of the whole coil, these ends being nowhere placed in a vertical position to each other, the danger of sparking through the layers of wire is reduced to a minimum when the coil is wound in divisions.

§ 37. Coils in Two or Three Divisions.—In planning an ordinary spark coil to give sparks from 1 in. to 3 in. in air, the formation of the bobbin must be taken into consideration if the secondary coil is to be divided. A shallow bobbin, just large enough to hold the core and the primary coil, should be first made, fitted with the core, wound with the primary coil, and coated with paraffined paper ready for the secondary coil. If an ebonite or paper-maché tube can be made to fit tightly over the primary coil, this will be found to be an improvement. The end pieces and the dividing discs must now be prepared and fitted on the tube. The tube covering the primary coil should be thicker at the ends, or the end pieces should thicken at their junction with the tube, and the thick part be chamfered off

to form a thin sleeve on the tube. The dividing partitions should also be thickened in like manner. These precautions are advised to prevent sparks passing to the primary coil from the end turns of the secondary coil, or from one division of this coil to the next division, under the dividing discs. It is also advisable to have the end pieces of the bobbin and the dividing partitions fully two inches in diameter larger than necessary to hold the wire, to prevent leakage over and around the edges of the partitions. The space thus left can be afterwards padded with cotton and covered with leather or sheet ebonite, to give a finished appearance to the outside of the coil. The dividing partitions may be made of wood soaked in paraffin, or of ebonite, or of papier-maché soaked in paraffin, or of discs of thin cardboard or thick paper soaked in paraffin and put together whilst hot. Special attention must be paid to the soundness and perfect insulation of the material employed, and also to the fit of the partitions on the tube covering the primary coil. The slightest flaw overlooked at these points may result in a thorough break-down of the coil. It is advisable to well baste the joints of the dividing partitions with hot paraffin, and to wind some paraffined soft cotton on each side to form a flange or sleeve, before winding the secondary wire. Before winding the secondary wire of a large coil, special attention should be paid to its quality and insulation, as directed in sections 15 to 18. Instructions for winding will be found in section 17. The coil must be wound in one direction, filling up one division before

passing on to the next, the outside or finish end of one division being connected to the commencing or inside end of the next division by soldering the two ends together, the joint being made over the finish end of each coil. These joints must be carefully insulated with soft silk thread run through paraffin, and the commencing end of each division should be basted with paraffin to ensure thorough insulation.

§ 38. VERY LARGE SPARK COILS.—When coils are required to give sparks 6 in. and upward in air, the difficulties attending their construction increase with each extra inch of spark desired. The enormous potential of the induced current enables it to break through all but the most perfect insulation, and send sparks along the lines of least resistance, which may be within the coil itself. This fact must be taken into serious and practical consideration when constructing a large spark coil. The electric stress is equally the same in all directions, vertically, from the last outside turn of the secondary coil to its first inside turn, and, laterally, from the commencing end at one terminal to the finish end at the other. Great care is always exercised to keep these last points far apart, to prevent sparking across the coil laterally, but the existence of equal vertical stress is not always considered, and yet this is the most dangerous of the two, for a spark is more liable to pass vertically from the outside to the inside of a coil than from one side to the other laterally. This liability to internal vertical sparking has led coil makers to construct large spark coils in a number of thin divisions,

each well insulated from the rest. As the potential of the induced current in one of those thin coils is never very great between the commencing and the finish ends, or between the top and the bottom layers in one such division or compartment, there is little danger of vertical sparking. The liability to lateral sparking is also reduced to a minimum, because the number of turns on one layer in each compartment is also very small, and these are separated from the next by a well insulated division. These divisions may be made of vulcanite, ebonite, or discs of paraffined paper. The number of these in a coil, and the distance of the divisions apart, must be determined by the size of the coil. In a coil to give from a 3 in. to a 6 in. spark, the divisions may be 2 in. apart, but for larger coils this space may be narrowed down to one inch or even less with advantage.

In the best made large coils, such as those made by Messrs. Apps, Siemens, and Halske, the tube, bobbin ends, and divisions are all made of vulcanite or ebonite. The tube, containing the primary wire and core, is made in the form of a long bobbin with a thread cut on the ends to screw into the end pieces or cheeks of the secondary coil bobbin or reel. It therefore forms, with the core and primary coil, the body of the reel. The walls of this tube may be from $\frac{1}{16}$ in. to 1 in. in thickness, but the end pieces should be not less than $\frac{3}{4}$ in. in thickness, and these may be also screwed on to the ends of the tube.* Rings or sleeves, of ebonite or

* See description of Siemens' and Halske's coil in § 46.

vulcanite, should be made to slip tightly on the tube, each ring forming the body of a compartment for a section of the secondary coil as shown at Fig. 63.

The dividing discs should also be made of $\frac{1}{16}$ in. vulcanite or ebonite fitting the tube. In building the coil, a sleeve of vulcanite is slipped on the tube and pressed against the end cheek; a disc is then slipped on the tube until it meets the shoulder of the sleeve;

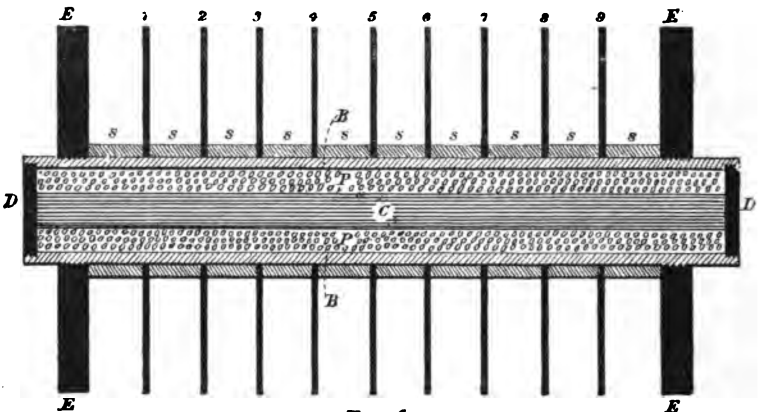


FIG. 63.

Section of Large Spark Coil built in Nine Divisions.

B.—Tube of Ebonite. *C.*—Core. *D.*—Screwed Ebonite Ends. *E.*—Ebonite Bobbin Ends. *s.s.*—Ebonite Sleeves.

another sleeve is then slipped on, then another disc, and so on, each disc being tightly pinched between the shoulders of two sleeves.

The following instructions on making induction coils, from the pen of Mr. A. Caplatzi, appeared in the *English Mechanic* of March 14th, 1890:—

"*The Divisions* are best made of vulcanite, and should

fit tightly over the tube. If circular cutters of the right size are at hand, divisions can be stamped out of half a dozen sheets of paraffined paper, stuck together. An uneven number—3, 5, 7, 9 divisions—should always be adopted, then the number of sections will be an even one, allowing the terminal wires of the end sections to appear on the top and farthest from striking danger. A slight cut for passing the wire is made in each division next to the tube, and the divisions should not be of more diameter than the coils they are intended to separate. The winding is started at the farthest end. Pass one end of the wire under division 1 (Fig. 63), then turn coil and handle to the right and wind to within ½ in. of, but not quite into, the corner, because there the tendency of the spark to strike into the primary is greatest. Now varnish or paraffin the layer and wrap two turns of paraffined foreign post paper round it. Wind, varnish, and cover the second and all following layers in the same way. Arrived at the top of section 1, cut, and turn one end round the terminal on top of the cheek, join the other to the bottom end in section 2. The joint need not be made there; you can bring the twisted ends out and draw them through molten solder; double a bit of paper over the joint and wind in, turning to the left this time. Arrived at the top, fasten temporarily, and pass wire end 9 inches through division 3. Wind and insulate section 3 as you did section 1 by turning to the right. When it is full, join end to end of section 2 at the top. Section 4 is wound same way as section 2 and so on, the end of the

wire in the last section being fixed to terminal on the right cheek. The odd sections are wound to the right and the even ones to the left. The result of that will be the same as if all the wire were wound from end to end in one direction, outwards and inwards, without the wire ever crossing. This is the only proper way of winding, no matter how many sections a coil may have. It is probably the easiest way of winding coils of moderate size. The sections of very large and heavy coils are not wound on the reel, but away from it, separately, and then pushed over the tube one after the other and tightened by screwing on the cheeks after them, taking particular care to join the ends coming from opposite directions together, so that the resulting winding may appear as above."

Mr. Caplatzi recommends soldering the joints with a pool of molten solder held in a depression made in a piece of sheet iron placed in the form of a bridge over a spirit lamp. This is probably a most convenient method for soldering fine wires. Clean the bared ends with a bit of emery cloth, twist them together to form a long joint, dip the joint in finely-powdered resin, then into the molten solder. The joint may be coated with soft silk to complete the insulation. If the wire is not wound into the corner of the first compartment, the vacant space should be filled with soft cotton soaked in paraffin, to level the surface for winding on the next layer of wire. Mr. Sprague recommends having the tube thickened at the ends, and the whole coil wound to take the form of an egg, to avoid the danger of

sparking through from secondary to primary. If a taper sleeve is fitted over the tube as previously directed, and the coil is wound in thin sections, it will not be necessary to have the ends of the tube thickened.

The following method will be found convenient for winding the sections of a large coil when discs of paraffined paper are employed for the divisions. Have the wire well soaked in paraffin, and the discs also well basted with the same material. Get a mandrel of metal made to the size of the intended body of the coil bobbin, and fit on this two discs of polished brass, equal in diameter to that of the paper divisions. These metal discs should be made to slip easily on the mandrel, which should be smooth for a length equal to the thickness of the intended section of the coil, but chased with a thread on each side of this smooth space, to fit two large nuts. A thin tube of ebonite or of paraffined paper is first put on the smooth part of the mandrel, then the discs of paper, then the metal discs, and the whole braced lightly together with the nuts. The compartment thus formed is filled with fine wire to form a section of the coil, and each layer must be well basted with melted paraffin. When this has been filled with wire, the whole must be first warmed to soften the paraffin, then made compact by tightening the nuts on each side of the metal discs. This done, the section must be allowed to get quite cool and hard. When quite cold, loosen the nuts and apply a hot iron to each metal disc until they come away freely from the paper discs, leaving the coil supported by them alone. Now

warm the mandrel on both sides of the coil and slip this off. Each section can thus be formed and slipped on the tube as already directed in Mr. Caplatzi's instructions. Care must be taken to have the secondary wire of large coils as perfect as possible, both as regards conductivity, continuity, and insulation. All joints must be well made and resin only employed in soldering them. For dimensions of large spark coils see Chapter V.

§ 39. SLEDGE COILS.—In the application of electricity to the diagnosis and cure of disease, it has been found necessary to have the means of regulating the volume

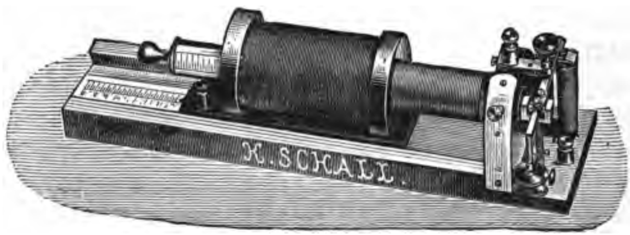


FIG. 64.

The Dubois-Reymond Sledge Coil.

and the tension of the reduced current to the fraction of an ampère and the fraction of a volt. Although this can be done by means of an ordinary medical coil, with a regulator tube over the core, or a sliding core, together with a set of resistances such as water regulator or other form of rheostat, and a lifting arrangement for the battery plates, all these methods of regulating the current may be enhanced or dispensed with by using the sledge form of coil invented by Dubois-Reymond, and shown at Fig. 64. In this

form of medical coil, the secondary wire is wound on a large bobbin with a hollow core capable of taking in the primary and the iron core. The primary wire is also wound on a separate bobbin with a hollow core, and is made to slide freely in the hollow core of the secondary bobbin. The hollow core of the primary bobbin may hold a fixed core of iron wire, but the coil is most useful when fitted with a sliding core as shown in the figure. The primary bobbin is fixed in a wood standard at one end of a long base board, and the connecting screws of the primary wire are held in this standard. The secondary bobbin is fixed to a small base made to slide as a sledge in runners attached to the long base of the instrument, and the connecting screws of the secondary wire are fixed to the sliding base of the secondary coil. The magnetic break is separate from the coil and is held on the end of the main base board, next the supporting standard of the primary coil. The sliding core may be made to work in the primary bobbin at either end, as may be deemed most convenient. A paper or metal scale of degrees on the sliding core, and on the base of the coil, will be found useful in determining the extent of movement ot the coil and core. This instrument must be well made and nicely fitted to ensure proper working, as all the parts should work with each other freely but not loosely. These instruments command a price ranging from two to five guineas.

The same principle of regulation may be adopted in making small spark coils, if so desired, but a coil con-

structed in this way is inferior to a fixed spark coil of equal weight and size, because power is lost in resistance of air space between the two bobbins of the coil and the regulating core.

§ 40. GAIFFE'S SLIDING COIL.—Another method of regulating the current is adopted by A. Gaiffe, of Paris. It is a medical coil of two powers, having two secondary coils made to slide over each other and over the primary coil, which is fixed and contains a fixed core. The contact breaker or rheotome is worked by the magnetism of the fixed core. A battery of two persulphate of

FIG. 65.

Gaiffe's Pocket Medical Coil.

mercury or of chloride of silver cells is enclosed in a neat box with the coil, and is connected to the primary coil by means of flexible wires and metal plugs which fit into metal connecting sockets on the edge of the box and on the supporting end of the primary. The price of this instrument ranges from 1 to 5 guineas. Gaiffe's pocket medical coil is shown at Fig. 65.

§ 41. COILS OF SEVERAL POWERS.—The Dubois-Reymond sledge coil, and the Gaiffe Sliding Coil, mentioned in the two preceding sections, may be

regarded as coils constructed to give a current of varying power, and will fulfil all the requirements of medical practitioners.

There is, however, another method of obtaining a varying and controllable current, employed by makers of street coils, that is, the shocking coils met with at street corners, at fairs, and at bazaars. This method consists of a medical coil made in the ordinary manner as shown at Figs. 14 and 15, p. 60, but with the secondary wire of the coil divided into several parts as shown at Fig. 15, p 65. The first secondary coil may consist of a wire a little smaller than that employed in the primary coil; the next of smaller wire still, and so on for as many coils as the powers desired, say in the following order—26, 28, 30, 32, 34, 36, 38, 40. A few layers of each size will suffice, and the coils are wound one over the other, forming when connected one continuous secondary coil. The primary coil may be included in the series as shown at Fig. 15, or may be left out. The method of winding and connecting is as follows. The first secondary coil is wound on in the usual manner, as described in preceding sections of this book, and the end of the last layer brought out to form a connection with a binding screw or terminal. If only one size of wire is to be used in the various powers, it will not be necessary to cut the wire, but it should be brought out to the length of a foot and doubled back on itself to form a loop, then twisted to form a cord of two strands. The end of this will be bared and cleaned to form a connection between the coil and terminal. After wind-

ing on enough wire to form the second power of the coil, the same method of making connection must be repeated, and so on to the end of the coil.

If wires of various sizes are employed, the first size is wound on, the end brought out, and the surplus cut off; this end is marked as the first power. A little piece of the wire at the first end of the last layer is bared and cleaned, and the starting end of the next size of wire, to form the second power, is twisted around the cleaned part, and soldered to form a junction with the first power. The second size of wire is wound on over the first in the same direction, and the finish end treated in a similar manner to that of the first power, but marked as the second power of the coil. The remaining powers of the coil are treated in a similar manner. The finish end of one power and the commencing end of the next power may be twisted together to form a cord, and the connection between the two made under the terminal screw if desired. Care must be taken to insulate each joint with paraffined cotton or silk before winding the wire. In mounting such a coil, the ends of the various powers are brought down through the base of the instrument under the coil, and there connected to the tangs of studs arranged in a semi-circle on the table on which the coil is mounted. The studs are numbered to correspond with the powers of the coil, and a cranked switch makes contact with each stud as required.

§ 42. THE PYKE-BARNETT INDUCTION COIL.—Through the kind courtesy of Messrs. Woodhouse &

Rawson, United, Limited, the proprietors of this coil, I am enabled to give an illustration (Fig. 66) and a description of the Pyke-Barnett Induction Coil, named by them the "flame spark coil." This coil may be regarded as an ordinary induction coil mounted in a vertical position, with its upper end improvised as a platform for the contact breaker. The coil is somewhat shorter and thicker than the usual run of spark

FIG. 66.

The Pyke-Barnett Patent Induction Coil.

coils, but does not differ in any other way from these. The contact breaker or rheotome presents some special features which demand attention, since they tend to minimise the spark at the break and also insure a very rapid action of this part. The hammer is worked by an electro-magnet in shunt circuit with the primary coil of wire. The primary circuit is broken by two contact

springs and studs, instead of one, as in the usual form of contact breakers. When the coil is at rest, both of these are in contact and keep the primary circuit closed. On connecting the coil with the battery, these contacts are slightly and instantaneously separated by the vibrating hammer, which opens each alternately. The following description of the action of this patent automatic break is given by Mr. Perren-Maycock in the *English Mechanic* of Nov. 7th, 1889, and is illustrated by the accompanying diagrams, Figs. 67 and 68. The

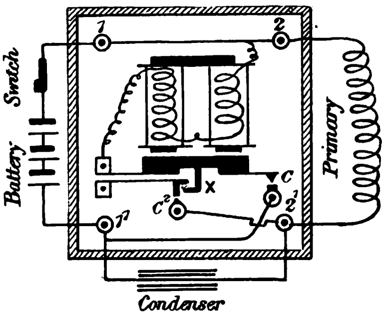


FIG. 67.

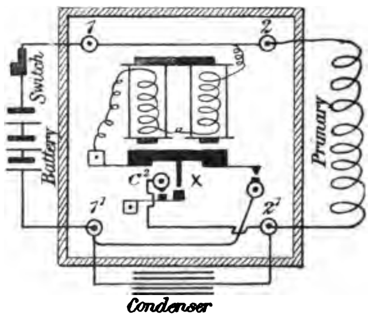


FIG. 68.

Diagrams of the Pyke-Barnett Automatic Break.

figures represent two patterns of this patent automatic break, and are copied in part from the specification drawing.

Starting from left-hand bottom terminal (1^1), one circuit goes viâ contact C, through armature and magnet coils to terminal 1. This is an ordinary "make and break," and is connected up as a shunt circuit to the battery, the main circuit going from terminal 1, viâ contact C^2, terminal 2^1, to primary coil and back to

battery through terminals 2 and 1. In each figure the armature carries a hook or stud ×, which is insulated at the tip. The vibration of the armature causes this stud to automatically open the main contact C^2; in the first case (Fig. 67) by a pull; in the second (Fig. 68) by a push. The condenser is joined to terminals 1^1 and 2^1. In the Pyke-Barnett coil the discharger is mounted vertically on the side of the coil.

§ 43. COILS CURIOUSLY MOUNTED.—In the collection of Mr. A. Caplatzi may be seen a few curiously mounted coils. One eccentric maker has mounted a spark coil on the neck of an ordinary bottle bichromate battery. An ebonite collar rests on the bulb of the bottle, and this bears four brass pillars supporting an ebonite platform containing a magnetic contact breaker, the platform forming the upper cheek of the secondary coil. Inside this is the primary coil, wound on the neck of the bottle. The usual lifting arrangements for the plates pass through an ebonite cover fitting in the centre of the platform. No possible advantage can be obtained from this form. It is merely a whimsical arrangement to insure compactness for storage in a box. In the same collection may be seen coils inserted in the backs of hair brushes. The brush has metal bristles inserted in metal plates which are insulated from each other. One set of bristles is connected to one terminal, and the other set to the opposite terminal of the coil. The back of the brush is hollow, and divided into two compartments, one of which contains a very small induction coil

mounted in ivory, and the other a very small chloride of silver battery. Similar small coils, worked with chloride of silver batteries, have been inserted in the hollowed handles of walking-sticks. Some of the old forms of gas-lighters were thus constructed: two wires running along the sides of the stick conveyed the induced current from the coil to two platinum points at the end of stick. By pressing a stud in the handle, the battery is switched on to the coil, and a spark passes from one platinum point to the other. Many other methods of mounting coils, to serve the fancy of the makers, or to suit various purposes, might be mentioned, but these do not affect the working of a coil if constructed on the principles already laid down.

CHAPTER V.

SOME FAMOUS COILS.

§ 44. MR. SPRAGUE'S LIST OF NOTED COILS.—Mr. Sprague gives in his book, "Electricity: Its Theory, Sources and Applications," the following list of noted coils:—

1. *Rhumkorff* has constructed some, containing about sixty miles of secondary, which with one Bunsen cell gave $3\frac{1}{4}$ in. spark, and 16 in. with seven cells.

2. *Ritchie* made one for *Gassiot*, the core 18 inches, $1\frac{3}{4}$ inches dia., the wire covered with gutta percha $\frac{1}{10}$ (inch), thick: the primary, 9 gauge, 150 feet in three layers. The secondary in three cylinders, each 5 inches long, made of gutta percha $\frac{1}{10}$ (inch?) thick; the wire of the middle one 32 gauge, 22,500 feet long; the others of 33, each 25,575 feet. There are three condensers, of 50, 100, and 150 feet, capable of combination. With five Bunsens, each coil gave a spark of 5 inches; the three gave $12\frac{1}{4}$ inches.

3. *Siemens and Halske.*—Made with a number of partitions of sheet ebonite, containing 80 miles of secondary, and gave sparks from 1 to 2 feet in length.

4. *Yeates.*—In two compartments; core, 22 inches by $1\frac{1}{4}$; primary, 12 gauge in 2 layers; secondary, No. 36 in 5 layers, making 55,000 turns, insulated with gutta percha tissue and paraffined paper, $10\frac{1}{2}$ miles in length and $10\frac{1}{2}$ lbs in weight; condenser, 66 sheets of foil 11×29, with paraffined paper. With five Grove cells it gave $12\frac{3}{4}$ inches spark.

5. *Ladd's.*—Core, 1 foot long, 1·8 inch diameter; primary 12 gauge, 50 yards in three layers; secondary, 3 miles, No. 35, in layers from end to end, each separated with five or six sheets of gutta percha tissue; condenser, 50 sheets of foil 18×8 on varnished paper; gives 5 inches spark with 5 Bunsens. One constructed for Dr. Robinson, with two secondary coils, each 5,690 yards, or together 6 miles 820 yards, is said to give sparks 2·44 in. with one cell; 5·46, with two; 6·45 with three; 7·65 with four; and 8·38 with five cells.

6. *The Polytechnic.*—Length from end to end, 9 feet 10 inches; diameter, 2 feet; weight, 15 cwt.; containing 477 lb. of ebonite. The core, 5 feet long, of No. 16 wire, 4 inches diameter, 123 lbs. The primary, 145 lbs. of 123 (·0925) 3,770 yards, making 600 turns in strands of 3, 6, and 12 wires; total resistance, 2·2014 ohms. The secondary, 606 lbs., 150 miles long and resistance 33,560 ohms, on an ebonite tube $\frac{1}{2}$ inch thick and 8 feet long, the coil itself occupying 54 inches in the middle of the tube. The condenser in six parts, each containing 125 square feet of foil. With five large Bunsen cells the spark was 12 inches, and 29 inches with 50

cells. Particulars of a series of experiments with this coil are given in *The Chemical News*, Sept. 24th, 1869. No. 513.

§ 45. REMARKS ON MR. SPRAGUE'S LIST OF NOTED COILS.—1. The information given here is imperfect, as it leaves out the size of secondary wire, but all other particulars respecting the construction of the coil show how the spark can be increased in length by increasing the number of cells.

2. Gutta percha is bad as an insulator, since it becomes hard and friable with age. The cylinder method of dividing the secondary is not nearly so effective as that of the disc method ; but may be adopted where a coil of three powers are required, each cylinder bearing a separate coil. In this form three condensers were desirable. It will be noted here, that one coil gave a spark of 5 inches, but the three when coupled together only gave a spark of 12¼ inches, or less than 5 × 3.

3. One wishes to have had more information about this coil, which appears to have given such good results, apparently due to improved insulation of the secondary wire by partitions of sheet ebonite. Further details of this coil are given in the next section.

4. This appears to have been a good coil, giving good results. Perhaps the number of condenser sheets might have been increased with advantage.

5. Although here again gutta percha tissue is used, the obtained results are good. The gauge of the primary was large for a foot coil, and might have been No. 16. Paraffined paper should be used alone as an

insulator. Dr. Robinson's coil shows how the length of spark can be increased by increasing the number of cells. This increase must, however, be made cautiously, and should proceed cell by cell, special care being taken when a coil is not divided into compartments or the insulation may be perforated by sparks.

6. This monster coil, being made by one of the best coil makers in England, calls for no remarks from the author, except that of admiration, for its short-lived performances. The subsequent break-down of this coil has been attributed (by Mr. J. W. Urquhart) to defective insulation consequent upon the use of gutta percha tissue as an insulator.* But Mr. Apps assures me that gutta percha was not used as an insulator. In a letter to me he says: "With reference to gutta percha, there was not an atom of it used in making the coil. The piercing of the tube was caused by a nervous operator letting the discharging tongs fall on the tube when connected with the 66 jar Leyden battery. I slipped the three tubes around so that the holes were not opposite, and all went on as well as before. There was no failure (proper) of the Polytechnic coil at all, the very unimportant piercing of the primary coil tubes at one end having been magnified by competitors in the trade to state falsely that the insulation had failed."

In the *Electrician* of Aug. 21st, 1891, Vol. XXVII., p. 433, Dr. J. A. Fleming thus describes the Polytechnic coil built by Mr. A. Apps: "The secondary of this coil was 150 miles in length. The diameter of the wire

* *Design and Work*, Vol. viii., p. 170.

was ·014 of an inch and it was silk-covered. This secondary wire was wound in grooves about ⅛ in. in width and 200 in number. The iron core was a bundle of soft iron wire, 4 in. in diameter, weighing 123 lbs., and about 5 ft. in length. The primary bobbin weighed 145 lbs. and consisted of 6,000 turns of covered copper wire ·095 of an inch in diameter and 3,770 yards in length. The secondary bobbin when complete had an external diameter of 2 ft. and a length of 4 ft. 10 in. The primary coil was insulated from the secondary coil by an ebonite tube. Excited by the current from 40 large Bunsen cells, this coil would give secondary sparks 29 in. in length, and could in a few seconds charge 66 Leyden jars, each having 11 square feet of internal coated surface. The secondary discharge could pierce blocks of glass 5 in. in thickness."

§ 46. MR. URQUHART'S LIST OF NOTED COILS.—In a series of excellent articles contributed to *Design and Work*, Vol. VIII., by Mr. J. W. Urquhart, this author repeats Mr. Sprague's list, and adds to it a few remarks of his own. The instruments of Messrs. Siemens and Halske receive commendation from him: "Their method of building is based entirely upon the multiple division system, and some of their coils contain as much as 80 miles of secondary wire. The divisions are of ebonite, as many as 150 being frequently placed upon a coil having a tube 2 ft. long. This tube is shaped so as to present a thickness considerably greater at the ends than at the middle, and upon it the dividing discs are placed at right angles." Mr. Urquhart gives the

details of Siemens' and Halske's coil mentioned by Mr. Sprague: "A number of iron wires 1·3 m.m. (·051051=No. 18) in diameter, and 95 centimetres (37·40245 inches) long, form the core, which has a diameter of 60 m.m. (2·3562 inches). Two layers of copper wire 2·5 m.m. (·088175=Nos. 13—14) diameter form the primary coil, which is wound over the core; the pair weigh together 35 lbs. They are placed in a tube of best ebonite 26 m.m. (1·02102 inches) thick at the ends, and 12 m.m. (·47124 inch, or nearly ½ in.) thick at the middle. Along this tube 150 thin discs of ebonite are fixed at equal intervals, and the ends are covered with thick discs of the same material. Each sub-division between the small discs is filled with a coil of silk-covered and varnished copper wire, 0·14 m.m. (·0054978=No. 35) in diameter; these coils are connected in series so that the current flows from the outside to the inside of one compartment, and from the inside to the outside of the next, in order that no two portions of wire at greatly different potentials may ever be in close proximity. In length the secondary wire is 10,755 metres (11,755 yds.), and it makes 299,198 turns around the cylinder. The weight of the secondary coil is about 58 lbs. With a battery of five large Grove or Bunsen cells, the sparks are nearly 2 ft. in length.

"Many coil makers prefer this multiple division plan to Fergusson's plan of one or two discs only, for the reason simply that it is nearly impossible to break such a coil down. In some cases, as will be seen, the plan advocated by Fergusson may prove best in careful hands,

and a larger spark may result from a few miles of wire, but the liability to rupture is so great, if the coil gives a long spark, that Siemens' plan carried out with paraffined divisions, instead of ebonite discs, proves the best for general use."

§ 47. APPS' LARGE INDUCTION COILS.—The prince of coil makers in England, and perhaps of coil makers universally, is Mr. Alfred Apps, who carries on the business of electrical, optical, mathematical and philosophical instrument maker at 433, Strand, London, W.C. Since the year 1867, when he patented some improvements in induction coils (British specification, No. 177, Jan. 24th, 1867) he has devoted particular attention to the production of large coils, and has made some of the most powerful induction coils in existence. In 1869 he built the large Polytechnic coil described in § 45. He next made a large coil for the late Mr. W. Spottiswoode, F.R.S., of Sevenoaks, which was made on the same lines as the Polytechnic coil, and gave a spark 18 inches in length. In 1876 he introduced several improvements in the manufacture of spark coils whilst building the colossal induction coil known as the Spottiswoode coil, this being built to the order of Mr. Spottiswoode. This coil is described in the next section. Several large spark coils were then made by Mr. Apps, among them being one for the Framjee Kawasjee Institute of Bombay, in which, by particular attention to insulation, he so far increased the power of spark coils as to get a 11 in. spark from a coil 8½ in. in length, or a spark 3½ in. longer than the bobbin of the coil! Particulars

of six coils made on the same scale by Mr. Apps for Lord Armstrong have been published in the *Electrician*, Vol. XXVII., p. 435. The measurements of these coils are: length of primary bobbin, 9·1 in.; inside diameter, 1·6 in.; outside diameter, 2 in. The primary coil consists of 51 yards of square No. 14 B. W. G. copper wire wound in four layers, making 366 turns and having a resistance of ·32 ohm. The length of the secondary bobbin is 8⅝ in., interior diameter 3$\frac{5}{16}$ in., and exterior diameter 5$\frac{7}{16}$ in. The secondary coil consists of 7 lbs. 1 oz. 7 drs. of ·0064 (about No. 39) silk-covered copper wire, measuring 8 miles 25 yards. It makes 41,425 turns, and has a resistance of 12,500 ohms. Each coil is furnished with a condenser divided into six parts, and is capable of giving a spark from 10½ to 11 in. in length. The most effective primary current for this coil is one of 12 ampères at a pressure of 10 volts. Dr. Fleming remarks that the details of the processes by which these remarkable achievements in insulation have been obtained, are of the nature of trade secrets, but generally it may be said that the greatest precautions have to be taken to secure such good results.

§ 48. THE SPOTTISWOODE COIL.—This remarkable coil, made by Mr. Apps and illustrated in our frontispiece and at Fig. 69, is thus described in the *Philosophical Magazine* for January 1887, p. 30, by Mr. Spottiswoode himself.

"The general appearance of the instrument is represented in the figure, by which it is seen that the coil is supported by two massive pillars of wood,

sheathed with gutta-percha and filled in towards their upper extremities with paraffin wax. Besides these two main supports, a third, capable of being raised or lowered by means of a screw, is placed in the centre, in order to prevent any bending of the great superincumbent mass. The whole stands on a mahogany frame resting on castors.

"The coil is furnished with two primaries, either of which may be used at pleasure. Either may be replaced

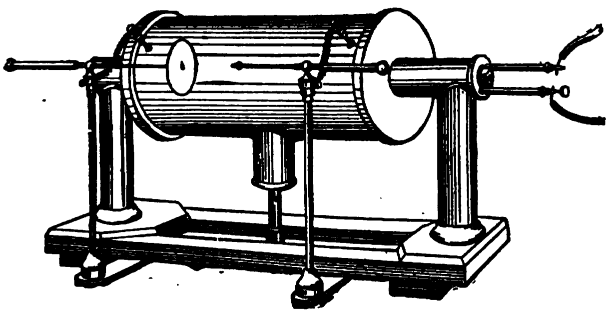


FIG. 69.

The Spottiswoode Induction Coil.

by the other, by two men in the course of a few minutes. The one to be used for long sparks, and indeed for most experiments, has a core consisting of a bundle of iron wires, each ·032 in. thick, and forming together a solid cylinder 44 in. in length and 3·5625 in. in diameter. Its weight is 67 lbs. The copper wire used in this primary is 660 yds. in length, ·096 in. in diameter, has a conductivity of 93 per cent., and offers a total resistance of 2·3 ohms. It contains 1,344 turns wound

singly in six layers, has a total length of 42 in., with an internal diameter of 3·75 in. and an external of 4·75 in. The total weight of this wire is 55 lbs.

"The other primary, which is intended to be used with batteries of greater surface, *e.g.*, for the production of short thick sparks, or for spectroscopic purposes, has a core of iron wires ·032 in. thick, forming a solid cylinder 44 in. long and 3·8125 in diameter. The weight of this core is 92 lbs. The copper wire is similar to that in the primary first described, but it consists of 504 yards wound in double strand forming three pairs of layers, whose resistances are ·181, ·211, ·231 ohm respectively. Its length is 42 in., its external diameter 5·5 in., and its internal 4 in. Its weight is 84 lbs. By a somewhat novel arrangement, these three layers may be used either in series as a wire of ·192 in. thickness, or coupled together in threes as one of ·576 in. thickness. It should, however, be added that, owing to the enormous strength of current which this is capable of carrying, and to the highly insulated secondary coil being possibly overcharged so as to fuse the wire, this larger primary is best adapted for use with secondary condensers of large surface, for spectrum-analysis, and for experiments with vacuum tubes in which it is desirable to produce a great volume of light of high intensity, as well as of long duration at a single discharge. The alternate discharges and flaming sparks can also be best produced by this primary. It has been used for high-tension sparks to 34 in. in air, the battery being 10 cells of Grove's with platinum plates 6¼ in. × 3 in. Great facili-

ties for the use of different sets of batteries are afforded by the division of this primary into three separate circuits, to be used together or separately; and by a suitable arrangement of automatic contact breakers the primary currents may be made to follow in a certain order as to time, duration, and strength, with effects which, when observed in the revolving mirror, will doubtless lead to important results in the study of striæ in vacuum tubes.

"The secondary consists of no less than 280 miles of wire, forming a cylinder 37·5 in. in length, 20 in. in external and 9·5 in. in internal diameter. Its conductivity is 94 per cent., and its total resistance is equal to 110,200 ohms. The whole is wound in four sections, the diameter of the wire used for the two central sections being ·0095 in., and those of the two external being ·0115 in. and ·0110 in. respectively. The object of the increased thickness towards the extremities of the coil was to provide for the accumulated charge which that portion of the wire has to carry.

"Each of these sections was wound in flat discs: and the average number of layers in each disc is about 200, varying, however, with the different sizes of wire, &c. The total number of turns in the secondary is 341,850.

"The great length of the wire necessary can be easily understood from the fact that near the exterior diameter of the coil a single turn exceeds 5 ft. in length. The spark, it is believed, is due to the number of turns of wire, rather than to its length, suitable insulation being preserved throughout the entire length. In order to

ensure success, the layers were carefully tested separately and then in sets, and the results noted for comparison. In this way it was hoped that step by step safe progress would be made. As an extreme test, as many as 70 cells of Grove's has been used, with no damage whatever to the insulation.

"The condenser required for this coil proved to be much smaller than might at first have been expected. After a variety of experiments, it appeared that the most suitable size is that usually employed by the same maker, with a 10 in. spark coil—viz., 126 sheets of tinfoil 18 in. × 8·25 in. in surface, separated by two thicknesses measuring ·011 in. The whole contains 252 sheets of paper 19 in. × 9 in. in surface.

"Using the smaller primary, this coil gave with five quart cells of Grove a spark of 28 in., with 10 similar cells one of 35 in., and with 30 such cells one of 37·5 in. and subsequently one of 42 in. As these sparks were obtained without difficulty, it appears not improbable that, if the insulation of the ends of the secondary were carried further than at present, a still longer spark might be obtained. But special adaptations would be required for such an experiment, the spark of 42 in. already so much exceeding the length of the secondary coil.

"When the discharging points are placed about an inch apart, a flowing discharge is obtained both at making and at breaking the primary circuit. The sound which accompanies this discharge implies that it is intermittent, the time and current spaces of which have not as yet been determined.

"With a 28 in. spark, produced by five quart cells, a block of flint glass 3 in. in thickness was in some instances pierced, in others both pierced and fractured, the fractured pieces being invariably flint glass. If we may estimate from this result, the 42 in. spark would be capable of piercing a block 6 in. in thickness.

"When used for vacuum tubes this coil gives illumination of extreme brilliancy and very long duration: with 20 to 30 cells and a slow-working mercury break, giving, say, 80 sparks per minute, the striæ last long enough for their forward and backward motion to be perceived directly by the unassisted eye. The appearance of the striæ when observed in a revolving mirror (as described in the "Proceedings of the Royal Society," Vol. XXV., p. 73) was unprecedentedly vivid, and this even when only two or three cells were employed.

"Further experiments have shown that with such large coils only the newly-discovered effects of very high temperature-combustion or volatilisation can be produced. On exciting the primary of the coil with a suitable dynamo-electric machine, or battery, and using a large Leyden jar in the secondary circuit (according to Sir William Grove's experiment), the electrical discharge passing between electrodes placed before the slit of the spectroscope, lines and bands may be observed to advance and recede according to the variations made in the magnitude of the exciting discharges. As the atmospheric pressure may be assumed to remain constant, these effects are probably due to differences of temperature arising from the action of a greater or

smaller extent of electrical effects on the electrodes in a given time."

§ 49. OBSERVATIONS ON NOTED COILS.—In a series of articles on the Historical Development of the Induction Coil and Transformer, published in the *Electrician*, Vol. XXVII., Dr. J. A. Fleming mentions other noted coils of more or less antiquated design. These are of some interest from an historical point of view, but a description of them would be matter outside the scope of this book. The noted coils already described in preceding sections will show the reader what has been and can be done in the manufacture of large coils. It will be seen that the best material for the tubes, ends, and dividing discs of a large spark coil is ebonite. The best method of insulating the primary from the secondary is to enclose the primary and core in a tube of ebonite on which is wound the secondary coil. The best method of preventing lateral and vertical internal sparking between the coils of the secondary is to build this in thin divisions or compartments, well insulated from each other. A high state of insulation has been obtained by immersing the finished coil in a bath of melted paraffin and allowing it to remain therein until quite permeated with this insulating substance. High insulating properties have also been obtained by enclosing the finished coil in a suitable vessel kept filled with a heavy mineral oil, the vessel forming an outer containing case for the instrument. It is possible to obtain sparks with a higher ratio of length than 1 in. to each mile of wire, if great care and skill is exercised in

the insulation of the wire. When wire is highly insulated, and special care taken in arranging and connecting the divisions of a large coil, it is not necessary to increase the area of the condenser in proportion to the increased size of the coil. This is seen in the famous Spottiswoode coil, which only required a condenser suitable to a 10 in. spark, even when a 42 in. spark was obtained from the secondary wire.

CHAPTER VI.

BATTERIES FOR COILS.

§ 50. SUITABLE BATTERIES FOR COILS.—Although induction coils may be actuated by a suitable current of electricity obtainable from any available source, and can therefore be worked with current from a dynamo, they are generally worked with current obtainable from voltaic batteries. In the minds of persons having little or no knowledge of coils and batteries, there exists a confused idea of the relation between a coil and a battery, some supposing that a coil will or should give shocks without a battery. To make matters clear to such persons, it will be well to explain that the battery stands in the same relation to a coil as that of a boiler to a steam engine. As the boiler without the engine will not drive machinery, nor an engine without a boiler, neither will a battery alone give those shocks and sparks obtainable from a battery and coil combined, nor will a coil be of any use without a battery to work it, since the battery is the source of power. This being established in the mind, we will go further and state that not only is a battery necessary to get effects from a coil,

but also a suitable battery must be selected to each variety and size of coil. This instrument, like all other electrical instruments, can only be efficiently worked when supplied with current of a suitable strength. If the primary circuit of the coil offers a low resistance to the current, as in the case when a short thick wire is employed to form the primary coil, the battery should also have a low internal resistance and be capable of furnishing a large volume of current. If the primary circuit offers a high resistance to the current, as when the primary coil is a long thin wire of many turns, we may employ a battery of high internal resistance, as in this case a large volume of current will not be required, but the E. M. F. or pressure of the current should be high to overcome the high resistance of the circuit. We may employ a battery having a low internal resistance, on a circuit having a high resistance, but should not use a battery having a high internal resistance on a circuit with a low resistance. In a choice of batteries, some regard must be paid to the nature of the work done by the coil. If the coil is to be worked continuously through long periods of time exceeding a quarter of an hour's run without stoppage, a battery of the constant current type will be required. If intermittent action of a feeble character only be desired, the battery cells may be small. If continuous and strong effects be required, as from a large spark coil, the battery must give a strong constant current, and the cells have a large capacity.

When the resistance of the primary circuit is low,

and the volume of current required should be large, we must employ large battery cells, having a low internal resistance, or connect the cells in parallel, which will have the same effect. Cells are connected in parallel to form a battery, when all the positive elements (all the zincs) are connected to one leading off wire, and all the negative elements to another wire.

When the resistance of the primary circuit is high, and we wish to push the current smartly through this high resistance, we must increase the E. M. F. (electromotive force) of the battery by connecting the cells in series. Cells are connected in series when the positive element in one cell is connected by a copper wire to the negative element in the next cell, and the positive element of this second cell to the negative element of a third, and so on, through the series of cells.

The following list of well-known batteries, given in order of merit, are suitable for working large induction coils: — Grove, Bunsen, Single-fluid Chromic Acid, Single-fluid Bichromate, Double-fluid Chromic Acid and Double-fluid Bichromate batteries. These are all of the constant current type, giving full volumes of current when large cells and large elements are employed.

The following list of well-known batteries, given in order of merit, are suitable for working small spark coils or large medical coils :—Single-fluid Chromic Acid or Bichromate; Large element Special Leclanché; Smee; Gassner and other dry batteries used in electric-bell work. These last give a fair volume of current for short

periods of time varying with the size of cell and freshness of the charge. The volume then falls, but may be restored by a short period of inaction.

The following list of batteries, given in order of merit, may be employed in working small medical coils and other small induction coils with a primary circuit of high resistance:—Leclanché, Gassner and other dry batteries, Mercury Persulphate, Chloride of Silver. All the batteries above-mentioned have been constructed in many varieties by various makers, who have given their names to special modifications of the batteries. It is almost impossible to make a correct list of all these modifications, some of which consist only of a mechanical device for connecting the elements, or a special shape to the cells, or the addition of some salt of mercury to the exciting solution. Some of these varieties will be mentioned in the following description of batteries, as they approximate to well-known types.

§ 51. The Grove Battery.—This battery, invented by Professor Grove, consists of a composite cell containing two elements in two distinct fluids, separated from each other by a porous earthenware partition. The outer cell may be of stoneware, porcelain, or glass, of a shape round, square, or rectangular, and a capacity of from one pint to one or two gallons. This cell contains the positive element of the battery, which may be a plate or a cylinder (as shown at Fig. 70), or a bent strip of thick sheet zinc well amalgamated with mercury, immersed in a solution of sulphuric acid composed of one part acid to eight or more parts of water up to fifteen

parts. The cell also contains another smaller cell of porous earthenware placed in the centre, where it is enclosed by the zinc cylinder, or between the plates of zinc. The inner cell is made of porous earthenware, a material resembling that employed in the manufacture of tiles and gardeners' flower pots, with its shape and size suitable to that of the outer cell. This porous cell contains a sheet of platinum foil immersed in strong commercial nitric acid. A connecting strip of zinc or other metal

FIG. 70.
Zinc Cylinder.

FIG. 71.
Porous Cell.

protrudes from the top of the positive element and is bent over the top of the next cell, where it overhangs the porous cell and forms a support for the platinum foil. The foil is clamped to this overhanging part, and is thus connected with the positive element of the next cell in series. The Grove cell has been largely employed in laboratories and by experimenters needing a strong current of electricity. The E. M. F. of its elements is 1·90 volts, and the internal resistance is low when large elements and large cells are employed, probably about 0·20 ohm.

§ 52. THE BUNSEN BATTERY.—This battery, invented by Professor Bunsen, consists of a composite cell containing two elements in two distinct fluids, separated from each other by a porous earthenware partition. The outer containing cell and the inner porous cell are similar in every respect to those employed in the Grove battery just described. The positive element and the solutions in both cells are also the same. It differs only from the Grove in having a plate or cylinder or bar of graphite, that is, of hard carbon similar to the scurf carbon obtained from gas retorts. In the older forms of the Bunsen cell, this carbon was moulded into the form of a cylinder, but, in the more modern forms, the carbon (negative) element is in the form of a square bar from 1 to 2 inches square, and of a length suitable to the height of the cell in which it is used. Round porous cells are employed to suit this form of carbon. Plates of carbon may be employed if square or rectangular porous cells are used. As carbon plates are cheaper than platinum foil, the Bunsen can be set up at less cost than that of the Grove battery. Connection with the elements is made with brass clamps sold for the purpose to suit the thick carbon or the thin zinc plates. (Fig. 72 shows the round form of cell, and Fig. 73 shows a battery of six flat cells.) The E. M. F. of its elements is from 1·80 to 1·86 volts, according to the strength and condition of the solutions. The internal resistance of the cells is slightly higher than that of the Grove, and may be put down as 0·30 ohm. Both the Grove and Bunsen—although powerful and constant batteries—

have one objectionable feature which prevents them from being general favourites. They both give off noxious and poisonous fumes of nitrous oxide whilst at work,

FIG. 72.
Bunsen Cell.

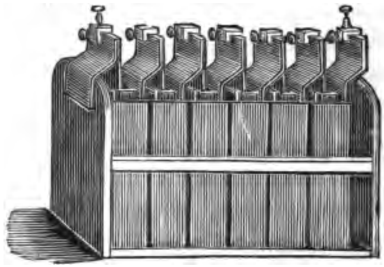


FIG. 73.
Bunsen Battery of Flat Cells.

and this makes their presence intolerable in a room or workshop unless placed in a fume closet well ventilated to carry off the objectionable odour.

§ 53. THE DOUBLE-FLUID BICHROMATE BATTERY. —This battery differs from the Bunsen only in the depolarising solution, that is the solution surrounding the negative element. In fact, if we empty the porous cell of nitric acid, and fill it with a solution of bichromate of potash, we shall convert the Bunsen at once into a double-fluid bichromate battery, the other fluid in the outer cell being the same as that employed in the Bunsen battery. The bichromate of potash solution is made in the following manner: "To eight pints of water add two pints of sulphuric acid. This mixture will get very hot. Whilst the mixture is still hot, stir into it

slowly one pound of finely powdered bichromate of potash. Use when cold. This is the "Electropoin Fluid" employed by Messrs. T. Gent and Co., of Leicester. When this solution is freshly made, it acts as an energetic depolariser. When its action flags, it may be revived by adding a small quantity of nitric acid. Bichromate of potash solution is a fairly good depolariser, and does not give off nitrous fumes whilst at work. In this property it is superior to nitric acid, but is not odourless, and the odour is objectionable to some persons. It is not so cleanly in working as nitric acid, for it stains the cells and connections with a dirty brown mud, and deposits crystals at the bottom of the porous cells.

§ 54. THE FULLER BATTERY.—If we reverse the position of the elements in a double-fluid bichromate cell, placing the zinc in the porous cell and the carbon in the larger outer cell, we obtain another modification of the Bunsen. The battery invented by Mr. Fuller is constructed on those lines. The zinc element may be in the form of a bolt with a lump like that of a dumb bell at its lower end, or a cone with a connecting wire of copper cast in its apex. The cone or lump of zinc is placed in the porous cell and covered with mercury. The cell is then filled with a dilute sulphuric acid solution, or with a mercurial solution, or (in some of the weaker forms of this battery) with water only. The negative element in the outer cell may be one or two plates of carbon. The cell may be charged with a saturated solution of bichromate of potash made acid,

with three ounces of acid to each pint of solution. As the zinc element is always standing in a pool of mercury, it is kept well amalgamated, and does not waste away when the battery is idle. The battery is therefore useful for occasional and intermittent work with small coils. The E. M. F. of each cell is about 1·50 volts, but the internal resistance is higher than that of the ordinary double-fluid bichromate battery.

§ 55. The Granule Battery.—In the year 1877 it occurred to the author and his brother, that the ordinary bichromate Bunsen might be considerably improved in point of constancy by exposing a very large negative surface of rough carbon to the bichromate solution. We therefore formed a circle of carbon lumps around the porous cell, and connected these together by a ring of lead to form one large negative element. A bolt of cast zinc was employed in the porous cell at first, but we found that the E. M. F. of the battery was considerably less when using cast zinc than when strips of rolled zinc were used as the positive element. We therefore had some zinc cylinders made to go in the porous cell, and found these an improvement on zinc bolts. As we were troubled with a deposit of crystals from the usual bichromate solution, we acidulated it with muriatic acid instead of sulphuric acid, and employed a solution of chloride of zinc in the porous cell with the positive element. This battery gave excellent results, and proved to be very powerful and fairly constant. It could be left for weeks together unused without destroying the zinc, and was always ready for use. We sub-

sequently ceased using it because it gave trouble in cleaning the cells and elements, which became encrusted with crystals, and because the chlorine fumes from it corroded the metal-work in the workshop.

Coincidently with our use of this modification, there appeared on the market a new battery patented by Mr. H. Dale, named the "granule battery," in which the lumps of carbon employed by us were replaced by a plate of carbon packed with granules of carbon or small pebbles of this material, all other features being the same as in our battery. This is now in use under the above name, and that of the "pebble carbon" battery. The granule cell has a slightly higher internal resistance than one in which a circle of carbon lumps is employed, but its behaviour is otherwise the same. Like all other bichromate of potash batteries, the E. M. F. is nearly two volts at first closing the circuit, but soon falls to 1·50 volts, remaining fairly constant at this until the depolarising solution is exhausted. The cells are difficult to clean and keep in working order, because of crystals of some chromic salt forming among the granules of carbon, and on the bottom of the porous cell.

§ 56. THE DOUBLE-FLUID CHROMIC ACID BATTERY.—If a solution of chromic acid is used in the porous cells of a Bunsen battery, instead of a solution of bichromate of potash, the battery then becomes a double-fluid chromic acid battery. A solution recommended by Mr. S. R. Bottone for this purpose is composed of commercial chromic acid 1 lb., chlorate of potash 2 oz., sulphuric acid, 7 oz., water 1 quart. The

addition of chlorate of potash improves the depolarising qualities of the chromic acid, and thus renders the battery more constant. Glass cells are preferable to those of stoneware or any other ware when chromic acid is used, as this has a powerful corrosive action on the cells and fittings. There are no noxious fumes arising from its use, and an absence of troublesome crystals in the cells.

§ 57. THE SMEE BATTERY.—This battery, invented by Mr. Alfred Smee, is a good type of the single-fluid series of batteries. It is composed of two or more cells made and fitted as shown at Fig. 74, and connected together. Each cell may be of glass, stoneware, or porcelain, and of any shape or size determined upon. The elements in each cell are a plate of platinised silver foil between two plates of zinc insulated from each other and suspended in the exciting liquid from a cross-bar of wood, the ends of which rest on the sides of the cell, as shown in the figure. The plates of zinc must be amalgamated with mercury, and are secured to the wood support by a brass clamp. The solution is one of dilute sulphuric

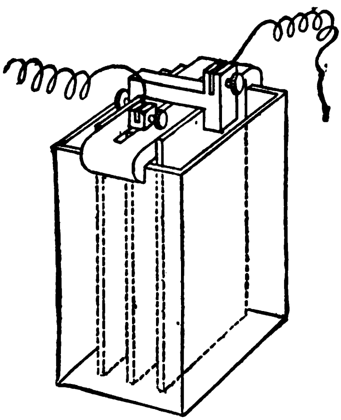


FIG. 74.
Smee Cell.

acid, in the proportion of one measure of acid to ten or fifteen measures of water. The clamp on the zinc plates of one cell is connected by a copper wire with the clamp on the silver foil in the next cell, and so on through all the series of cells which form the battery. This battery has been much used in working small medical coils, but it cannot be said to be a very powerful battery, as the E. M. F. of its elements is only about half a volt, and, as it readily polarises on a closed circuit, it does not give a current of constant strength. It has the merit of working cleanly and giving little trouble to mount or dismount its elements, the cross-bar with its depending plates being lifted out of the solution when the battery is not required.

§ 58. THE WALKER BATTERY.—If a plate of platinised carbon be substituted for the silver foil, and is suspended from the cross-bar between two plates of zinc, the Smee cell is converted into a Walker cell, the invention of Mr. Walker, a telegraph superintendent of the South-Eastern Railway. The Walker cell is slightly superior to the Smee in having a higher E. M. F. and a lower internal resistance, and also costing less in construction. Although the cells may be of any shape or size, the half-pint capacity, rectangular shape, is generally employed in a battery for a small medical coil.

§ 59. THE SINGLE-FLUID BICHROMATE BATTERY.—If a plate of plain carbon is used in the Walker cell instead of a plate of platinised carbon, and the cell is charged with a solution of bichromate of potash instead of dilute sulphuric acid, it is known as the bichromate

cell. It is found to be more economical to reverse the position of the elements and enclose a zinc plate between two carbon plates, as then both sides of the zinc plate are rendered effective in generating the current, and both sides are equally worn. As bichromate of potash has a tendency to crystallise out of its solution and creep up over the plates and connections, these should be arranged for easy removal of the plates for cleansing purposes, and it is advisable to have the zinc plate reversible, so as to be able to reverse the ends and wear both ends. If a cross-bar of wood is made to support the plates, as shown in Fig. 74, the zinc plate can always be easily slipped in and out of the central slit when the brass clamp on the carbon plates has been removed.

In the single-fluid cells sent out by Mr. K. Schall with his portable medical coils, the clamps are at the ends of levers hinged to the sides of the battery box. The side edges of the plates are connected by these clamps instead of the top edges, and their depth of immersion can be easily regulated or one of the plates withdrawn at any time without disturbing the connections of the others. This is a great convenience, both for cleaning the elements and also for regulating the volume of current from the battery.

When a large battery of this type is desired, as for working a large spark coil, it is advisable to still further increase the surface of the negative element by enclosing the zinc between four carbon plates arranged in the form of open V's on each side of the zinc. This is done

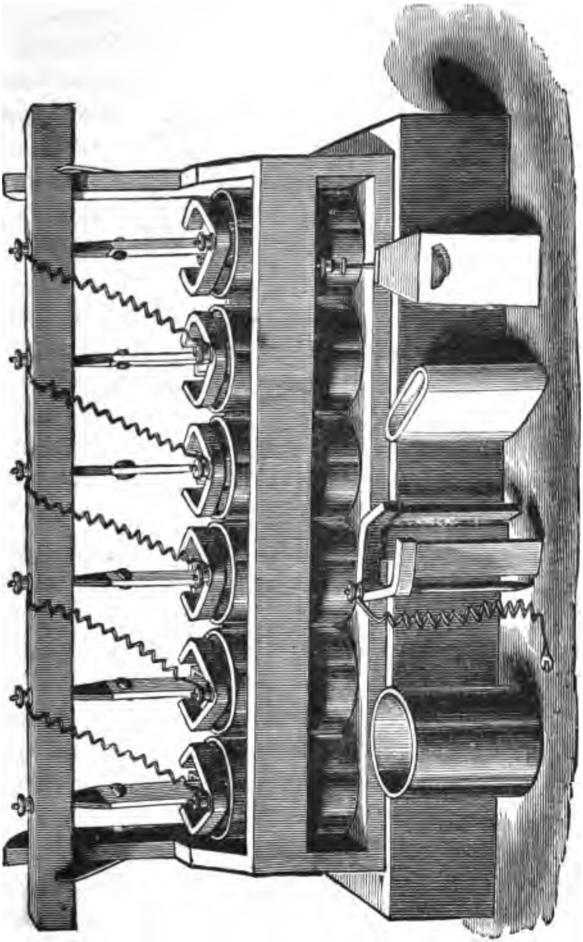


FIG. 75.
Gent & Co.'s Large Bichromate Battery.

in the large battery sent out by Messrs. T. Gent & Co., Faraday Works, Leicester, and shown in the accompanying illustration, Fig. 75. This battery is really one of the double-fluid type, but can be worked as a single-fluid battery by removing the porous cells. It will be seen from the illustration that the four carbons are cast in a connecting bar of lead, and the zinc element is a massive wedge-shaped piece of zinc provided with a projecting cup near the top to hold some mercury for the purpose of keeping the plate well amalgamated. It may be noted here that the zinc plates in bichromate of potash solutions are specially liable to local action and consequent destruction when the battery is not in use. They must therefore be well amalgamated with mercury and kept in this condition by frequent renewals of the mercurial coat.* They must also be lifted out of the solution when not in actual use. The solutions employed in a single-fluid bichromate cell may be either of the following :—

No. 1. *Bichromate Solution.*—Finely powder 3 oz. of bichromate of potash and dissolve it in 1 pint of boiling water contained in a glazed earthenware or a stoneware vessel. Allow this to cool, then add in a fine stream, or drop by drop whilst stirring with a glass rod, 3 fluid ounces of sulphuric acid, *i.e.* oil of vitriol. This solution must be allowed to get quite cold before being placed in the battery cell, or it will violently attack the zinc.

No. 2. *Chromic Acid Solution.*—Add 3 oz. of chromic

* The addition of 2 oz. persulphate of mercury to each gallon of solution will assist in keeping the zincs in good condition.

acid to 1 pint of luke-warm rain water and stir with a glass rod until all the crystals have been dissolved. Then add gradually, as before, 3 fluid ounces of sulphuric acid. This solution must also be allowed to get cold before using it in the battery cells.

No. 3. *Chromic Acid Solution.*—Prepare a dilute solution of sulphuric acid in the proportion of one measure of the acid to 12 measures of water, then add five ounces by weight of chromic acid to each quart of dilute acid, stirring all together until the chromic acid crystals are all dissolved. Allow this solution to cool before placing it in the battery cells or it will waste the zinc plates.

The Single-Fluid Bichromate Battery has undergone several alterations and modifications in the hands of inventive users. These modifications consist mostly in arrangements of the elements for easily lifting them out of the solution, or shape of the various parts to meet the requirements of portable medical coils and of cabinet coils. Among many others might be mentioned Dr. Spamer's and Dr. Stoehrer's batteries, specially arranged for compactness; Reiniger's battery, in which the connections are made by fusing or soldering them together; Voltolini's battery, in which the zincs are cast with mercury to obviate the necessity of amalgamation; and Gaiffe's plunge battery, in which the elements are arranged for easy removal from the cells by lifting the cover of the box in which the battery is placed. The Poggendorf battery is also a bichromate battery. All of these may be worked with a chromic acid solution.

§ 60. THE BOTTLE BICHROMATE BATTERY.—This is merely a handy form of a single-fluid bichromate cell, made in the form of a bottle, as shown at Fig. 76. A cover of polished hard wood is fitted to a collar of brass which fits the neck of the bottle like a sleeve or like the cover of a canister. Two carbon plates, long enough to nearly reach the bottom of the bottle, is secured to the cover by two binding screws, the tangs of which pass down into lead heads cast on the carbons. Between these lead heads is fixed a socket or sleeve of brass, into which fits a brass rod made to slide stiffly in the socket. One end of this rod is screwed into a zinc plate half the length of the carbon plates, and the other end terminates in a milled head of brass. The socket in which this rod slides is connected by a strip of brass to one of the connecting pillars on the cover, whilst the other pillar is attached to a strip of brass spanning the binding screws of the two carbon plates. When the battery is not at work, the zinc plate may be lifted out of the solution by pulling up the sliding rod of brass, care being always taken in charging the cell to have the solution just one ½ in. below the lower end of the zinc when thus drawn up.

FIG. 76.
Bottle Bichromate Cell.

At Fig. 77 is shown a more powerful form of the same cell, which consists of a glass jar, like a confec-

tionery jar, fitted with a hard wood cover from which is suspended three carbon plates and two zinc plates in the spaces between the carbons. The sliding rods and the connections are similar to those in the other form of cell. The space between the surfaces of carbon and zinc need never exceed ½ an inch. The zincs must be well amalgamated, and this must be frequently renewed. Any single-fluid bichromate or chromic acid solution may be used in these bottles or jars. The E. M. F. of each may be put down at 2 volts, and the internal resistance as from 0·02 to 0·08 ohm. Any number of these cells may be connected to form a battery.

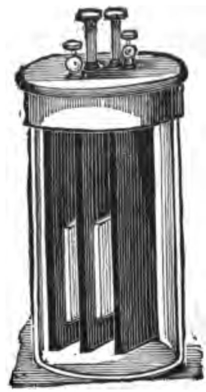


FIG. 77.
Double Plate Bichromate Cell.

Single-fluid bichromate of potash and chromic acid cells have the advantage of being easily set up and charged, and giving a powerful current when the circuit is first closed. But they soon polarise, and consequently the force of the current diminishes after the circuit has been closed for a few minutes, and this is specially noticeable when the resistance of the circuit is low. Chromic acid is superior to bichromate of potash as a depolariser. The cost is about 1s. per lb.

§ 61. THE LECLANCHÉ BATTERY.—This battery, the invention of M. Georges Leclanché, consists of a glass cell of special shape (resembling a wide-mouthed bottle with square sides, as shown at Fig. 81) enclosing a cell

of porous earthenware fitted with a carbon rod packed with a mixture of equal parts of binoxide of manganese and carbon broken to the size of peas and sifted free from dust. The carbon rod has a lead head cast on it, enclosing a binding screw for connection, as shown at Fig. 78. The top of the cell is sealed with pitch, and the carbon head painted with Brunswick black. A rod of zinc (Fig. 79) with a copper wire cast in it for connection, forms the positive element in the outer cell,

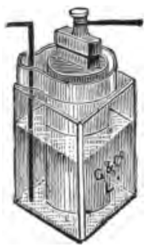


FIG. 81.
Leclanché Cell.

FIG. 78.
Carbon Plate.

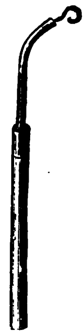


FIG. 79.
Zinc Rod.

which is charged with a half-saturated solution of sal-ammoniac in rain water. The depolariser in this cell is the binoxide or peroxide of manganese, and the exciter is the sal-ammoniac solution. The E. M. F. obtained from zinc and carbon under these conditions and in this solution, may be put at about 1·50 volts. The internal resistance of the cells varies very much with their size, from 0·90 up to 1·50 ohm. This battery, originally intended for ringing electric bells, has undergone several

modifications in the hands of its inventor, and those of manufacturers and users. The use of manganese peroxide as a depolariser, and sal-ammoniac as an exciter, enables makers to construct batteries which may be kept in working order ready for use for months or years without waste of zinc or corrosion of connections. They are thus specially suitable to the work of actuating medical coils.

§ 62. THE AGGLOMERATE LECLANCHÉ BATTERY.—This modification of the Leclanché cell, by the inventor himself, consists in the use of agglomerate blocks of manganese powder, carbon, and other substances, instead

FIG. 80.
Agglomerate Leclanché Cell.

FIG. 81A.
Medical Cell Sealed.

of porous cells. The blocks are formed under great heat and pressure by a patent process. A rectangular block is placed on each side of the usual carbon element and secured in close contact with it by rubber bands, as shown at Fig. 80. This arrangement has been modified by several makers. Messrs. T. Gent & Co., Faraday

Works, Leicester, compress the agglomerate mixture into the form of a cylinder 6 in. in length by 3 in. in diameter with a projecting lug of carbon, capped with lead and fitted with a binding screw in the usual manner. Another modification is shown at Fig. 82. The central carbon is fluted and a round block of the agglomerate

FIG. 82.
Six-Block Agglomerate Cell.

material is fitted into each of the grooves, all being bound together with rubber bands. The advantages obtained by the use of these blocks are, a considerable reduction of the internal resistance of the cell (which is stated to be 0·50 ohm for the ordinary shape and 0·20 for the fluted shape) and a consequent larger volume of

current obtainable from the cell. This advantage over the old form of Leclanché cell renders it useful for working the larger sizes of medical coils and spark coils of moderate size.

§ 63. MODIFICATIONS OF THE LECLANCHÉ BATTERY. —The invention of M. Leclanché has received a good deal of deserved attention from battery users, and a large number of modifications have consequently been introduced. These may here be briefly mentioned. 1. *Reversed Leclanché.*—In this cell the position of the elements is reversed, the zinc rod being placed in the porous cell, this being packed in the outer cell with the usual carbon and peroxide of manganese mixture. By this means a lower internal resistance is secured and the negative element is increased. 2. *The Applegarth Corrugated Carbon Cell.*—This modification, invented and patented by Mr. R. Applegarth, but now the property of D. Judson & Sons, consists in the use of a carbon cell, corrugated inside, as the negative element. At the bottom of the cell is a layer of manganese peroxide. The zinc rod is suspended in the cell from a stoneware cover, which insulates it from the carbon. Both the round and square forms of this cell are shown at Figs. 83 and 84. There is no porous cell required, and it may be

FIG. 83.
Corrugated Carbon Cell. Round Form.
A—Section of Cell.

FIG. 84.
Corrugated Carbon Cell. Square Form.

made semi-dry by packing the zinc rod with cotton-wool saturated in strong sal-ammoniac solution. Mr. Applegarth used this form for portable medical coils. 3. *The Austin-Leclanché Cell.*—Mr. H. E. Austin described in *Work*, vol. ii., a modification of the Leclanché cell devised by himself. A zinc plate is enveloped in several folds of white blotting paper and placed in the centre of a stoneware jar. On each side, at the distance of ½ an inch, is placed two carbon plates capped with lead in the ordinary manner. The whole is packed with the usual carbon and manganese mixture. 4. *Lacombe's Central Zinc Battery.*—In this form, shown in section at Fig. 85, the porous pot is replaced by a carbon cylinder resting upon a glass foot. The zinc rod is contained in a perforated tube in the centre of the cylinder, and the space around this tube is packed with the usual carbon and manganese mixture. The internal resistance of this cell is said to be lower than that of the ordinary Leclanché. It is

FIG. 85.
Lacombe's Central Zinc Cell. Section.

FIG. 86.
Gent & Co.'s Insulating Leclanché Cell.

sold by Messrs. T. Gent & Co., Leicester, a special form with flat zinc plates being made for working coils, &c. The same firm supply a patent insulated outer cell for the Leclanché battery, as shown at Fig. 86. The edge of this cell is in the form of a shallow trough, which is kept filled with oil and thus prevents the troublesome exosmose or creeping over of the sal-ammoniac salts.

5. *Leiter's Battery*.—This is a closed cell made of ebonite in rectangular form, 1 ft. 6 in. by 1 ft. 6 in. by 5 in. A cylinder or case of ebonite or gutta-percha perforated with longitudinal slits holds the zinc element. The remainder of the cell is packed with lumps of manganese ore and lumps of carbon in contact with a carbon plate. The cell is charged with the usual sal-ammoniac solution. There have been also several other modifications of the Leclanché cell by Tyer, Marcus, Binder, Lister, Gaiffe, Clark & Muirhead, and other users of batteries.

§ 64. REMARKS ON THE LECLANCHÉ SERIES OF BATTERIES.—In the construction of this series of batteries, the best results are obtained with a large negative element in close contact with the depolariser, which is, in this cell, peroxide of manganese. As peroxide of manganese is an inferior conductor of the current, and the grains of this ore are of irregular form, presenting many small angles instead of plane surfaces for contact, it is advisable to use large grains and sift these free from dust or wash them before using the ore. The same remarks apply to the grains of carbon employed in the packing mixture which are used to form a conducting medium between the grains of manganese

ore. The solution of sal-ammoniac should be concentrated, because in this form it offers less resistance to the current. It should be made with rain water instead of river or spring water, so as to prevent the introduction of lime. It is not necessary to amalgamate the zinc rods, but they work better and last longer when they are amalgamated with mercury. Rods cut from best rolled sheet-zinc, or strips of this material, work better than rods of cast zinc, last longer, and give better results. Care must always be taken to thoroughly insulate the two elements from each other above solution line, as the smallest leakage in the circuit soon exhausts the manganese of its depolarising properties. Cells of this class may not be left on short circuit or on a closed circuit for any length of time, nor should they be worked on a circuit of less resistance than the internal resistance of the battery. The battery keeps in working order longest when the cells are kept in a cool damp place.

§ 65. DRY BATTERIES.—Although the Leclanché series of batteries are less troublesome to keep in order than those of the acid type, and the solution of sal-ammoniac does not cause injury to clothes, carpets, and furniture when spilled, there always remains the danger of making a mess with the spilled liquid, even when the cells are sealed, for it is impossible to have them air-tight and water-tight, as a vent must be provided for the gases formed by the decomposition of the solution. Hence the cells must always be kept right side up, and must be examined to see that they contain

solution before connecting them to a coil. These inconveniences attending their use with portable medical coils, has led to a desire for a battery that will not spill its liquid when capsized, or the cells be broken by an accident. This desire has been gratified by the invention of several forms of so-called dry batteries, that is, those in which a paste supersedes the use of a liquid as an excitant. In the older forms of dry batteries, the zinc element was enveloped in several folds of blotting paper moistened with a solution of a deliquiscent salt such as zinc chloride, and separated from the negative element by the same material. Following this, came cotton wool, peat moss, sawdust, and similar absorbent materials soaked in the exciting solution and packed around the positive element. All these have a high resistance, which increases as the damp material dries, and crystals of the exciting salt form in the pores and crevices of the absorbent. This drawback led to the use of pastes of a deliquiscent character, some of which will be now noticed.

Scrivanow's Dry Battery.—In the Scrivanow dry cell, the carbon plate is coated with a paste composed of an ammonium-mercuric compound 10 parts, sodium-chloride 3 parts, silver chloride ¼ part, moistened with a solution of chloride of zinc. The paste is covered with several folds of blotting paper moistened with a solution of zinc chloride and common salt, and the zinc plate is laid on the blotting paper which serves as a porous partition between the two elements. The whole is bound tightly together and enclosed in an ebonite cell.

The Gassner Dry Battery.—This battery, the invention of Dr. Gassner, is composed of a zinc canister filled with an exciting and depolarising paste surrounding a central element of carbon. The zinc canister forms the outer containing cell and positive element combined, its inner surface being exposed to the action of the exciting ingredient of the paste which it contains. This paste is a patented and secret preparation composed mainly of gypsum and oxide of zinc, together with some chloride of zinc and sal-ammoniac solution.

FIG. 87.
Sealed Dry Cell.

The carbon cube or cylinder forming the negative element is pressed into the pasty mass after this has been placed in the canister, and the paste is coated or sealed with a bituminous compound. The canister may be of any shape or size, the general form being similar to the sealed dry cell shown at Fig. 87; those for medical coils being of *rectangular* form. The E.M.F. of each cell has been stated as 1·50 volts, the internal resistance of the larger cells is lower than that of Leclanché cells of equal size, and the battery does not polarise so quickly as the Leclanché. The cells may be placed in any position, and work equally well whether standing on end or lying on their sides. They are not injuriously affected by extremes of heat or cold, and may be regenerated, when exhausted, by passing a strong electric current through them from carbon to zinc for a few hours. They are very suitable to portable

medical coils, but cannot be recommended for large coils. Messrs. T. Gent & Co. are agents in England for the sale of this battery. The same firm make a dry battery of their own, which they name the "Perfect Dry Battery," shown at Fig. 88. Messrs. Siemens Brothers, Limited, also supply a dry battery under the name of the "Hellesen Dry Battery." Other manufacturing electricians (as S. Coxeter & Son) also supply dry batteries of their own make, some of which bear a strong resemblance to the Gassner dry battery.

FIG. 88.
The "Perfect" Dry Battery.

The E. S. Dry Battery.—The Electric Stores Co. have also brought out a dry battery under the name of the E. S. Dry Battery, which has been commended by Mr. Bottone.

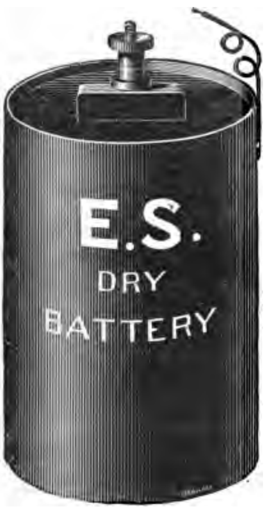


FIG. 89.
Electric Stores Dry Cell.

This battery (a cell of which is shown at Fig. 89) bids fair to merit the name of a Perfect Dry Battery. The E. M. F. of its elements is about the same as that of the Gassner, but the internal resistance of each cell is much lower for equal sizes, and the depolarising action more perfect. As a consequence, the current obtainable

from a battery of the E. S. cells is much stronger than that obtained from Leclanché or Gassner cells of equal size, and the current is also more constant. A battery of three E. S. cells of the larger size shown in the annexed figure will work a coil giving an inch spark, and two such cells will work a medical coil.

§ 66. CHLORIDE OF SILVER BATTERIES.—In 1860 Marie-Davy suggested the use of silver chloride as a depolariser. In 1868 Messrs. Warren de La Rue and Müller put this suggestion into practice by fusing some silver chloride around a silver wire and employing this as the negative element opposed to unamalgamated zinc as a positive element in a solution of common salt. Subsequently the Warren de La Rue chloride of silver battery appeared in the form of several small cylindrical cells, each containing a strip of silver coated with fused silver chloride and a strip of unamalgamated zinc in a solution of sal-ammoniac. The E. M. F. of such a pair is 1·03 volts.

M. Gaiffe improved the form of this battery, and made it portable by enveloping the elements with filter paper soaked in a solution of zinc chloride, and enclosing them in an ebonite case. Such batteries are sold with small medical coils imported from the Continent. In 1880 the battery was still further improved, and in this form is described by M. Niaudet in his "Traité Elementaire de la Pile Electrique." In 1889 Mr. K. Schall, of Wigmore Street, London, made several important alterations in the construction of this cell, by which he obtained a higher E. M. F. and a greater constancy of

current. In his improved form of cell, shown at Fig. 90, a plate of silver, imbedded in fused silver chloride, is suspended from the tightly-fitting ebonite lid of a glass jar by a silver wire. From the same lid is suspended an amalgamated zinc rod guarded from contact with the silver plate by rubber washers. Evaporation and

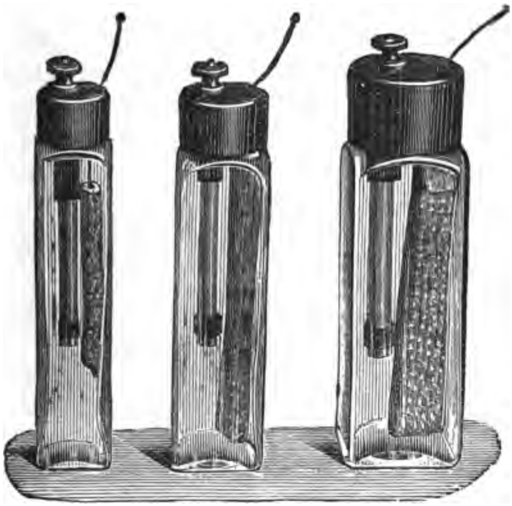


FIG. 90.

Mr. Schall's Improved Silver Chloride Battery.

spilling of the solution is prevented by rubber washers around the connecting wires, where they pass through the lid, and the gases formed by decomposition in the cell are liberated by a small safety valve. The E. M. F. of each pair is 1·7 volts and the internal resistance of each cell is 0·3 ohm. Mr. Schall claims for his batteries

that they are smaller, lighter, and more portable than any other battery of equal power. There is no chemical action while the circuit is interrupted. They may be left idle for many months without injury, because there are no crystals formed, and the cells consequently keep their original strength for years if they have not previously been exhausted by actual use. For this reason

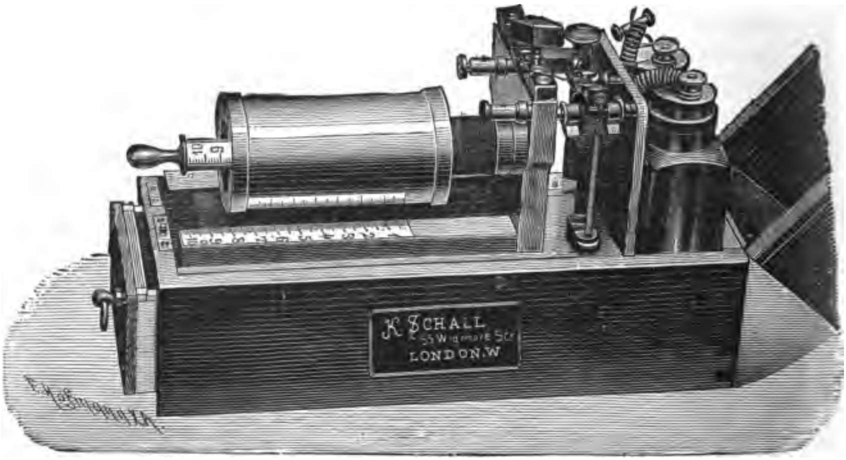


FIG. 91.
Dubois-Reymond Sledge Coil and Silver Chloride Battery Combined.

they are always ready for use and require very little attention. The cells are made in various sizes, from 1 in. square × 5 in. in height, up to 2½ in. square × 6½ in. in height, with a weight, when filled, of from 4½ oz. up to 40 oz., according to size. The smaller size will furnish 1 ampère hour of current, and the larger size 20 ampère hours of current with one charge. When the charge is

exhausted, it may be renewed and a new silver plate put in the cell at a cost of 8d. for the smaller size up to 2s. 9d. for the larger size. The size No. 106, measuring 1½ in. square × 5 in. in height, and weighing 12 oz., is recommended for working medical coils, and the larger sizes for electric cauteries and small electric lights. These last could also be used for working large coils. Fig. 91 shows its adaptation to a Dubois-Reymond medical coil.

§ 67. SULPHATE OF MERCURY BATTERIES.—Small portable medical coils and batteries imported from the

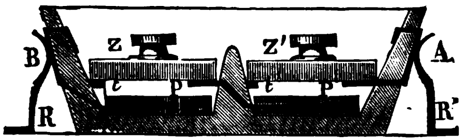


FIG. 92.

Section of Marie-Davy Battery.

A.B.—Contact Springs. *R.R'*.—Connections. *P.P.*—Platinum Supports to Zincs. *C.C.*—Carbons. *Z.Z'*.—Zinc Plates. *t.t.*—Mercury Sulphate.

Continent are frequently fitted with a small trough battery of two cells. These are generally of the Marie-Davy sulphate of mercury pattern, as shown in section at Fig. 92. The trough is made of ebonite divided in the centre by an ebonite partition to form two cells. The carbon C in the left-hand cell is connected to a platinum wire, which is attached to the contact piece B and connects this element with the curved spring R. The space above the carbon plate T is filled with a paste of bi-sulphate of mercury in water, and on this is

laid the massive zinc cover Z, which forms the positive element of the cell. This cover rests on a projecting lug of ebonite on the left-hand side, and a spring of platinum P on the right-hand side, this same spring going through the ebonite partition to the carbon plate in the next cell, thus connecting the zinc of one cell with the carbon of the next. In the next cell a platinum support for the zinc connects this at A with the curved spring R^1, which, together with the spring at the other end, forms the two terminals of the battery. The cells are merely filled with water up to the top of the zinc covers. The sulphate of mercury performs the part of a depolariser, and as it decomposes into metallic mercury and sulphuric acid when the battery circuit is closed, it furnishes an excitant for the zinc, and mercury to keep this element amalgamated. This is a very constant form of battery. The main drawback to its general use lies in the well-known danger of employing a poisonous salt of mercury, and the high price of this article. The elements in this battery have an E. M. F. of 1·52 volts, and the resistance of each cell is from $\frac{3}{4}$ to 1 ohm.

The Schanschieff Battery is also a sulphate of mercury battery, in which carbon and zinc plates are immersed in an acidulated solution of mercury sulphate. In the *Latimer-Clark Battery*, a layer of pure mercury forms the negative element, and zinc the positive element, immersed in a solution of mercury sulphate over the negative element.

Many other forms of primary battery cells might be

mentioned, belonging to the Daniell or Sulphate of Copper series, but these are rarely if ever employed by the users of induction coils, since, although they are excellent batteries where constant currents are required, they are troublesome to keep in order when only employed intermittently as in working induction coils.

§ 68. ACCUMULATOR OR SECONDARY BATTERIES.—These powerful batteries are eminently suitable to the work of actuating induction coils of all classes, but their construction does not come well within the province of the coil maker—amateur or professional—since most, if not all the processes by which the modern and best forms are produced are covered by existing patents. In the ordinary form of accumulator cells, the current is generated by an exchange of oxygen between two plates of lead, one of which is coated with finely-divided or spongy lead, and the other coated with a peroxide of lead, both formed by an electrolytic process necessitating a strong current of electricity. The plate coated with spongy lead is the negative, and the plate coated with lead peroxide is the positive element of the battery. The relative position and condition of these plates are reversible by the same electrolytic process employed in forming them, that is to say, when balance of potential is restored in the cell by the spongy lead on the negative being converted into lead oxide, and the higher oxide on the positive plate being reduced, we can make the negative plate again give up the oxygen it has absorbed and transfer it back to the erstwhile positive plate. This is named "charging" the

cell, and is done by sending a strong current through the acid solution in the cell, from the negative to the positive plate, for several hours. The plates are prepared in the first place by perforating sheet lead of $\frac{1}{16}$ in. thickness with a number of small holes, so as to form a sieve-like grid, as shown at Fig. 93, and to press into these holes with a wooden spatula a paste made up of

FIG. 93.
Sectional Elevation of an Accumulator.

lead oxide (litharge) and sulphuric acid. When the paste has become firm, the plates are placed in cells made of glass, stoneware, ebonite or similar acid-proof material, and the cells are charged with a solution of one part sulphuric acid in ten parts of water, or, more strictly speaking, a dilute solution of sulphuric acid having a specific gravity of from 1·170 to 1·130.

The pasted plates are then formed into negative and positive elements by the electrolytic process just described. Any number of plates (according to the capacity of the cell) may be placed in one cell at distances of ½ in. apart, but one half of the number must be positive and the other half negative, connected alternately to form one series of positive plates on one conductor, opposed to a series of negative plates connected to the opposite conductor. The two elements in one cell have an E. M. F. of 2 volts when fully and freshly charged, the capacity of each cell being calculated at the rate of 6 ampère hours for each square foot of positive element in the cell. It will thus be seen that a suitable dynamo or similar powerful generator of electricity is needed in making accumulators, and this must be used to re-charge the cells when they are exhausted.

Full information on making, charging, and working accumulators will be found in a book on Electric Light Installations, by Sir D. Salomons, published by Messrs. Whittaker & Co., at 6s.

§ 69. LITHANODE BATTERIES.—This series of batteries, invented and patented by Mr. Fitzgerald, and now owned by Messrs. Cathcart, Peto & Radford, 57B, Hatton Garden, E.C., have for their negative elements, plates of a substance named lithanode. This is an oxide of lead combined with some binding substance and compressed by suitable machinery into plates resembling close-grained carbon plates in substance, but of a reddish brown colour. The plates are very

friable, and will not bear being connected to brass clamps in the ordinary manner, they are therefore sent out with platinum foil connections clamped with ebonite collars and screws. When a cell is furnished with one of these plates opposed to a similar plate of amalgamated zinc in the ordinary battery solution of dilute sulphuric acid, the E. M. F. of each pair is 2·35 volts, and cells having a measurement of $3 \times 1\frac{3}{4} \times 4\frac{3}{4}$ have a capacity

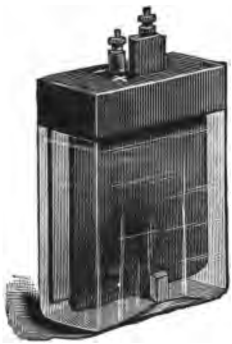


FIG. 95.

Lithanode Cell.

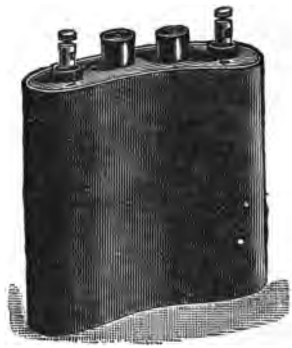


FIG. 94.

Pocket Accumulator.

of 4 ampère hours. When the lithanode plate has become exhausted of its surplus oxygen, it may be replaced with another plate, or the cell may be recharged as an accumulator by sending a small volume of current through it from a primary battery or a small dynamo. Lithanode plates are also used by the same firm in the manufacture of their well-known pocket and portable accumulators. The cells of these are made of ebonite with acid-proof

covers and stoppers, the pocket variety shown at Fig. 94 being curved to fit the coat breast-pocket of the wearer. They are employed with small portable electric lights for surgical and other purposes, for which they are admirably suitable, and are equally useful for working induction coils.

CHAPTER VII.

REPAIR OF COILS AND BATTERIES.

§ 70. Repair of Batteries.—As the motive power for induction coils is obtained from batteries, the positive elements of which are consumed to generate the electric current, these parts of the apparatus will need most frequent repair and renewal. The repairs and renewals will differ with each type of battery employed, and are here summarised.

Bunsen and Grove Batteries.—The negative elements of carbon and platinum in these batteries may be regarded as indestructible by acid. When carbon plates and bars are broken, they cannot be serviceably mended, but must be renewed. The brass connecting clamps on the carbons are liable to corrosion by the nitrous fumes rising from the acid. These fumes attack the threads of the screws and dissolve them. To prevent this, clean the screws in warm water, washing off all the green dirt, then dry in hot sawdust, and oil the screws, or dip them whilst hot in melted paraffin, wiping off the surplus with a rag. If the corrosion has been allowed to dry in the screws, they should be soaked in very dilute sulphuric

acid solution (1 part acid in 30 to 40 parts of water) until the corrosion has been loosened. No attempt should be made to loosen corroded screws until they have been thus soaked in dilute acid for an hour or more. The whole clamp may be thus protected, care being taken to clear off the oil or paraffin from the inside of the clamp where it has to come into contact with the carbon. These instructions apply to the binding screws and terminals of all batteries. The zincs must be taken out of the cells after each run, and brushed clean in the battery acid, then rinsed in water. If bare grey spots appear on the plates or cylinders, they must be re-amalgamated with mercury. When the nitric acid in the porous cells ceases to fume, and is clear or colourless when poured out of the cells, it is no longer of any use, and must be thrown away. The dilute sulphuric acid may be used several times if care be taken to keep it free from nitric acid.

Double-Fluid Bichromate and Chromic Acid Cells.— The foregoing remarks apply to these also. Whilst the depolarising solution remains yellow, orange, or a light brown, it may be used again, but when it turns black or green, it is of no further use, and must be thrown away. Every part of this battery must be well washed with water before putting it away, and the porous cells must be left always standing full of water in water. Should crystals form in the cells, dissolve them in warm water before attempting to move the zinc or carbon embedded in them, or the porous cells may be broken in the attempt. These remarks apply equally to all the

double-fluid bichromate and chromic acid batteries, and specially to the *Fuller* and the *granule carbon* forms of them. If lead heads are employed on the carbons, they should be frequently cleaned by brushing them in hot water, and re-painted with Brunswick black when dry. Paraffin is no protection to metal when chromic acid is used in the solution. If the lead heads become loose, they must be melted off, and new heads cast on the carbons. Keep all connections free of touch with the chromic acid solution.

Single-Fluid Chromic Acid and Bichromate Batteries. —Special attention must be paid to the amalgamation of the zincs in those batteries. They may need re-amalgamating after each time of using them, until the zinc gets well permeated with mercury. The plates should be reversed frequently, so as to wear both ends alike. The lead heads on the carbon plates will need frequent examination, for the chromic salts are very liable to crystallise out of the solution and creep up over the zincs and carbons, destroying in their course all connections. The acid solution becomes useless after it turns dark brown, black, or green. *Smee and Walker Batteries.*—Little need be said respecting the repair of these. The zinc plates should be kept well amalgamated, and should be made to easily remove for reversal. If the acid is spilled on the woodwork it will soon rot this. The wood supports should therefore be kept dry and well varnished. Torn foil must be renewed with new foil. Corroded screws should be soaked for some hours in dilute sulphuric acid before attempting to

move them. *Leclanché Batteries.*—When the current fails through exhaustion of the charged porous cells, it does not repay labour and time expended in clearing out and recharging the old cells. The cells may therefore be broken to get out the carbon plates, and these may be used again in new cells with a fresh charge of manganese and carbon. If Leclanché cells are placed on a short or leaky circuit they soon become exhausted, the sign of this bad treatment being, invariably, a strong ammonia odour from the battery, small white excrescences on the zinc rods and the porous cells, a deposit of these on the outer cells, and in bad cases an undermining of the lead head on the carbon, the ammonia forming with the lead a white paste resembling the white lead of commerce. If this has not gone on too long, so as to cause an entire exhaustion of the cell, it may be repaired by pouring away all the old solution, and soaking the whole cells and zinc in dilute muriatic acid until all the white lumps have been dissolved. Brush the zinc rod with a stiff brush, to clear off all traces of dirt, then amalgamate it afresh with mercury. Well wash the porous cell and drain off the dirty liquid inside, then recharge the outer cell with a new sal-ammoniac solution. Finally clean all connections afresh and give the cleaned head of lead a fresh coat of Brunswick black.

Agglomerate Leclanché Batteries.—These are easily repaired with new agglomerate blocks instead of the old cnes, and new or clean zinc rods and a fresh solution. It may also be necessary to use new rubber bands. The

solution in all Leclanché batteries should always be kept up to its original height by an occasional addition of rain water, with sometimes a little sal-ammoniac solution instead; but lumps of sal-ammoniac should never be added to the solution. If it appears to be thick, and seems to have lost its strength, it is best to throw the old solution away, clean the cells and zincs, and charge them with new solution.

Gassner and Other Dry Batteries.—Batteries of the recuperative type, such as the Gassner and others of its class, become exhausted after several hours' hard work, varying in time with the class of cell employed and the resistance of the circuit. In the high resistance circuit of a small electric bell, some 120 hours' work has been got out of a Gassner battery. When thus run down, they may be recuperated by sending a 1 ampère current through the cells from carbon to zinc for about 10 hours from a dynamo, or more powerful primary battery, such as the Bunsen. The E.M.F. of the charging current should be 2 volts for each cell charged in series. No renewals of solution or of zincs are required, but it is sometimes advisable to drill a hole in the seal and pour in 2 oz. of water before recharging a spent cell. The connecting wires soldered to the zinc cases of these cells are liable to be broken off. A new wire must then be soldered to the zinc, or, better still, a binding screw, such as those used on the zincs of other batteries. In arranging these dry cells in series to form a battery, care must be taken not to let their metal cases touch each other. The Gassner cells are sent out in a protecting

cover of oiled paper, and this should be left on the cells.

A dry battery of compact form, the invention of Mr. Coxeter, is in use by Messrs. Coxeter and Son, 4 and 6, Grafton Street, Gower Street, London. Small cells of rectangular form contain narrow plates of zinc and narrow plates of carbon, the elements being separated by a pad of gelatine saturated with the depolarising and exciting solutions. The E.M.F. of each pair is set down as 1·4 volts, and the internal resistance of each cell as ·6 ohm. This compact and very portable battery is employed in working portable medical coils, and as a medical battery without the use of a coil. From 40 to 60 such cells are placed in a small box under an ebonite platform on which is mounted a set of switches so arranged as to allow of any number of cells being thrown into circuit through a galvanometer, and thus the direct current given in measured doses, or the induced current from a small coil as may be desired. Used with a water rheostat in circuit, the direct current from this battery may be safely employed in delicate surgical work on the human brain.

Chloride of Silver Cells.—In process of working these cells, the chloride of silver on the silver wire or plates becomes reduced to metallic silver, when the cell is exhausted. The silver plate must then be taken out and cleaned (care being taken to preserve any powder obtained from cleaning the plate, as this will contain silver), and the plate must then be coated with fresh-

fused silver chloride. This substance is obtained by dissolving silver in dilute nitric acid until the acid is saturated with metal, then adding a solution of common salt to this as long as a white precipitate is thrown down. When this has been done, pour off all the acid and pour water on the precipitate; allow this to settle, then pour off the water. Do this several times, and then wash the chloride of silver precipitate, finally draining off all the water and leaving a paste. This (dry) chloride of silver paste may be spread on the plates and fused on them in the flame of a spirit lamp or that of a Bunsen burner, or, if means are at hand for doing so, the paste may be fused in a porcelain vessel and the silver coated with the fused chloride by dipping the wire or plates into it. Mr. K. Schall makes arrangements with his customers for the return of exhausted plates, and can exchange for new plates; this is a great convenience to users of chloride of silver cells. In the older forms of cells it is only necessary to take off the blotting-paper or other wrappings from the elements, and renew both paste and wrappings. All dirt and paper from these cells should be saved and sold for silver sweep, or fused with carbonate of soda to recover the silver. The zincs will need occasional cleaning and amalgamating if not of the zinc-mercury alloy type; the solution will also need renewal, and all connections should then be cleaned. *Sulphate of Mercury Cells* will need a similar treatment. Where a mercury paste has been employed, the cell must be well washed with hot water and the metallic mercury poured off, if any is

found in the cell. The paste must be renewed, and care taken not to handle this with the naked hands, as it is very poisonous.

§ 71. AMALGAMATION OF ZINC.—Owing to the unequal composition of the zinc plates employed in batteries, some parts being harder than others, and impurities being present in the zinc, galvanic couples are formed in the plates, which occasions local galvanic action in the cell. This wastes the zinc, which goes on dissolving when the circuit is not closed. To prevent this, the zinc plates or cylinders should be coated with mercury, which amalgamates with the zinc and presents an alloyed surface to the acid, not liable to local action, Several methods of effecting this have been proposed from time to time, but I have found the following method most efficacious in practice, and least troublesome. If the zinc plates or cylinders are new, their surfaces may be greasy, and this must be loosened in hot water in which some washing soda has been dissolved, then rinsed off in clean warm water. If the zincs are old and corroded, the corrosion must be cleared off by soaking the plates in dilute sulphuric acid and brushing them with a stiff brush. The clean zincs are then immersed in a solution of 1 part sulphuric acid in 5 or 6 parts of water contained in a shallow stoneware, glazed earthenware, or porcelain dish, such as a baking dish. Add the acid slowly to the water in the dish. The mixture will be scalding hot, and this high temperature will induce the mercury to spread over the zinc. Pour some mercury in the dish over the zincs

and move them about in the pool of mercury, rubbing this metal on them with a mop made of tow or flannel with some fine copper or brass wire waste intermixed. This wire will draw the mercury along over the zinc, and greatly facilitate the process of amalgamation. When the zinc plate has been coated with mercury in every part, lift it out of the acid, rinse it in clean water, and brush off the superfluous mercury with a stiff brush into a vessel. The insides of cylinders must have special attention, because these are the parts subject to wear and tear. The superfluous mercury drained off from the zincs should be placed in a bottle for future use.

§ 72. BINDING SCREWS.—The connections of the several parts of an electric circuit are usually made with brass appliances named binding screws, several patterns of which are shown in the annexed illustrations (Figs. 96—100), kindly lent me by Messrs. King, Mendham & Co., Western Electrical Works, Bristol. Referring to these—No. 56 shows a form of binding screw for the zinc element of a battery; 55, 58, 59 and 60 show forms of clamps for the carbon element of a battery; 79, the pillar connection of a bichromate cell; 51, 52, 53 and 54 are useful connectors for loose wires or temporary substitutes for joints; Nos. 1 to 11 show terminal screws for coils, suitable for insertion in hard wood; 12, 14 and 18 are more suitable for soft woods. Nos. 25 to 31 show the telegraph pattern of terminals for coils. Nos. 39, 40 and 44 show pillars for bell and coil rheotomes, and No. 48 shows a contact break or

rheotome complete. Nos. 34, 35, 38 and 41 show terminals suitable for galvanometers. Nos. 42 and 49 show studs for switches of coils, and 71, the switch arm.

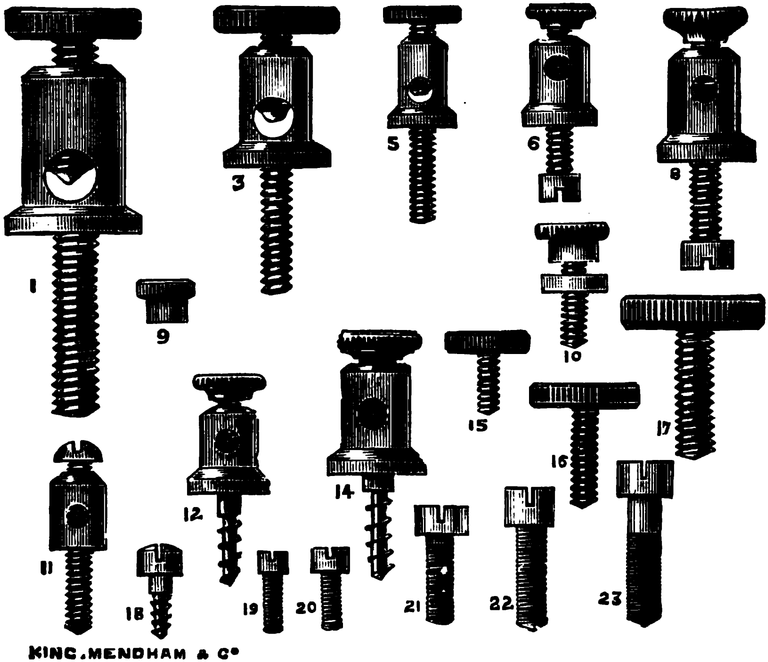


Fig. 96.

Group of Terminal, Binding, and other Brass Screws.

Nos. 70, 75 and 76 show quadrant hooks and other fastenings for false bottoms of boxes, and galvanometer cases. The shapes of the other figures explain them-

selves—being screws, hammer heads, &c. &c., used in electric bells. All are shown full size.

§ 73. SOLDERING.—Some knowledge of soldering is

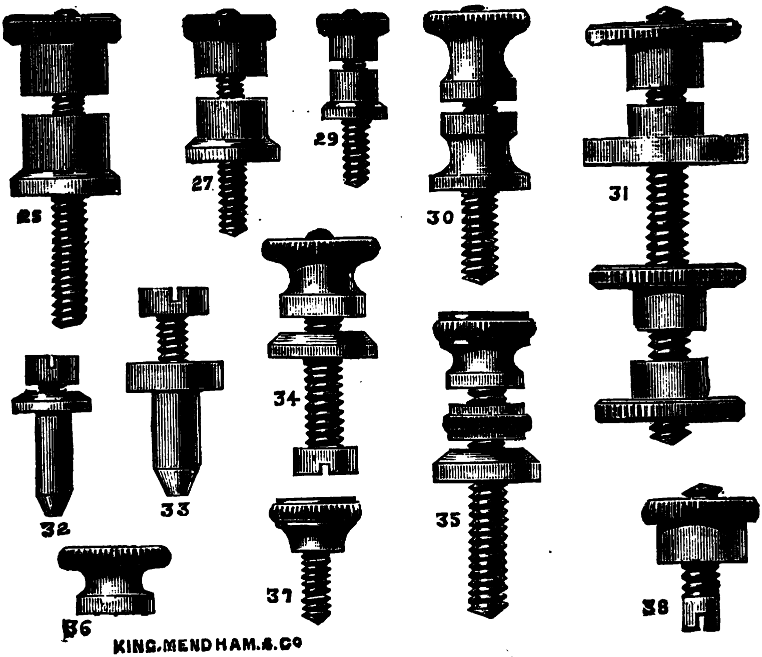


FIG. 97.

Group of Terminal Screws and Studs.

essential to the amateur coil maker. Uniting metals by soldering their surfaces together may be done by several methods, the most simple and easy being that of soft-soldering. As this will meet every likely emergency

I shall confine myself to suitable instructions for this method of soldering. Soft solder is an alloy of tin and lead, which is cast in sticks or strips, and sold at most hardware shops at a low price. It has the property of

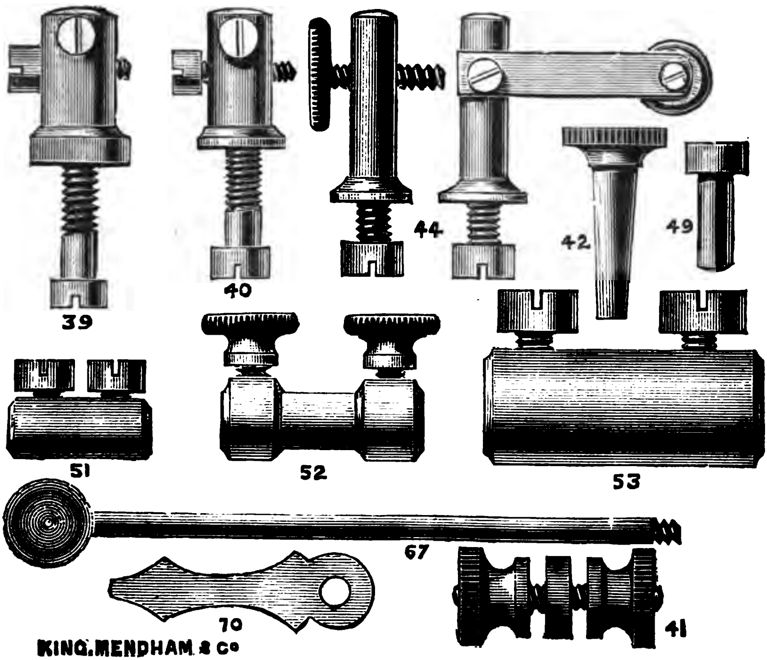


FIG. 98.

Group of Break Pillars, Connectors and Accessories.

melting at a low temperature and adhering firmly to the cleaned and prepared surface of any other metal. It may be readily melted with the heat given off from a red-hot bolt of copper. A tool known by the name

of a soldering bolt or soldering iron, composed of a bolt of copper held in the socket of an iron handle, is the tool in general use for soft soldering. The end of the copper bolt is filed to form a blunt point with four

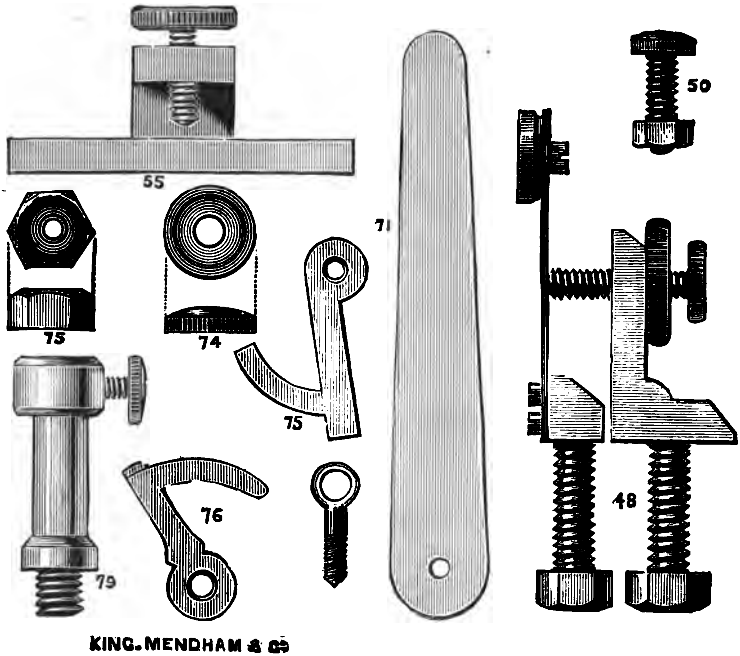


FIG. 99.
Group of Accessories to Coils.

facets, it is then heated in a fire or on a gas-stove until red-hot, the oxide of copper formed in heating the bolt is cleaned off with a file, and the clear hot facets made to take a coat of solder by one of the following methods,

Either dip the tip of the bolt in soldering fluid and rub it in the hollow of a fire-brick with some solder, or melt some solder with it in a hollow made in a lump of sal-ammoniac, and rub the facets in this until they are

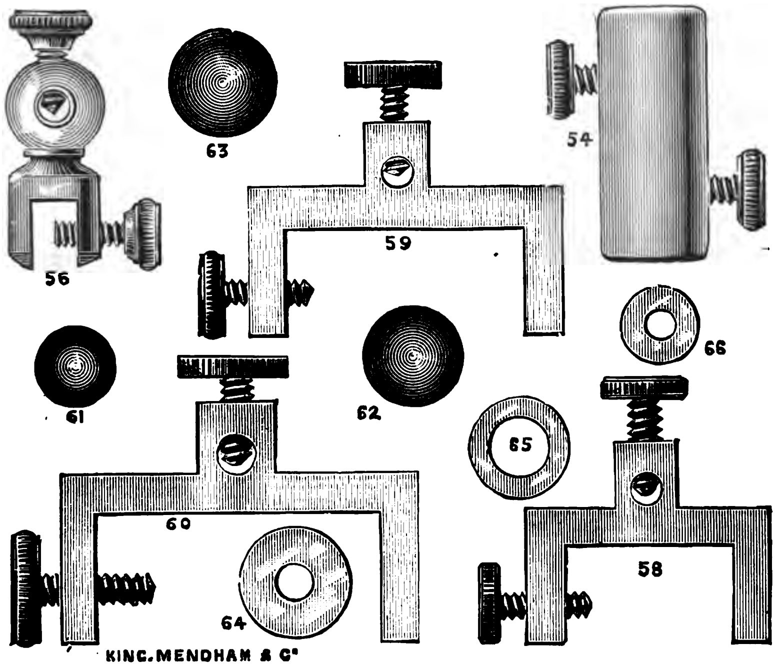


FIG. 100.

Group of Battery Clamps and Binding Screws.

coated with solder. The bolt must be of a dull red heat whilst doing this, or hot enough to freely melt the solder. When thus coated with solder, the tool is said to be tinned and can then be heated without oxidising the

facets, providing the copper be not over-heated. To soft-solder metals with this tool, the surfaces to be united must be thoroughly cleaned from grease and corrosion by means of a piece of emery cloth, then protected from oxidation by coating them with a suitable flux. Soldering fluids are sold for this purpose, but the amateur can easily make his own soldering fluid by dissolving scrap zinc in muriatic acid (spirits of salts) to saturation, then dilute it to twice its bulk with clean rain-water. Such a fluid may be used as flux for soldering copper and brass. Apply the fluid with a feather or chip of wood to the cleaned surface of the metal to be soldered, then rub the prepared spot with the heated soldering tool recently tipped with solder. The surface will at once take on a thin coat of solder, and, by pressing the heated tool on the article to be soldered, the two prepared surfaces may be united. If zinc has to be soldered, the flux should be crude muriatic acid only. If tinned articles are to be soldered resin may be used as a flux, and this also may be used in soldering copper. Resin only may be used in soldering the tinfoil of condensers, and it is advisable to employ this alone as a flux when soldering the wires of a coil. If the ordinary soldering fluid is employed here, the joint should be well washed afterwards to clear it entirely of chlorine, or this will corrode the joint and cause subsequent trouble. Paraffin wax has been employed as a flux for copper, pewter, and lead. When soldering fine wires, it is advisable to keep a little pool of molten solder at hand on a heated iron, and also a

little melted resin. Clean the ends of the wires by drawing them through a bit of emery cloth, twist the ends of the wires together to form a joint, dip the joint in the resin and then in the molten solder. The flame of a blow-pipe may be used instead of a soldering tool, if the workman is expert in the use of the blow-pipe. Only the softest and most easy-running solder should be used in soldering tinfoil and in making fine wire joints.

§ 74. Coppering Carbon Plates.—Connections may be soldered to the carbon plates of batteries if the carbons are first coated with copper. This may be easily done in the sulphate of copper compartment of a Daniell cell. Suspend the carbon plate in the concentrated solution of copper, and connect its upper part to the zinc element in the porous cell of this battery. The carbon may also be coppered in an electrotyping solution by a separate battery. The portion of carbon immersed in the sulphate of copper solution will become coated with copper as the zinc dissolves in the porous cell. When a sufficient coat of copper has been obtained, soak the carbon in hot water to free it from copper salts, and dry it at once. The coat of copper may be tinned and soldered in the usual manner, described in the preceding section.

§ 75. Repair of Coils.—Coils are liable to injury from various causes. A few of the most likely and prominent causes may be stated here, together with the methods to be adopted in repairing the injuries.

Loss of Insulation through Damp.—If coils are

allowed to get damp, the insulating medium between the turns of wire will be converted by moisture into a conductor, and the sparking properties of the coils will fail. If a coil gives a diminished spark from this cause, detach it from its base and all connections, well warm it before a fire, and then immerse it wholly in a bath of molten paraffin, keeping it there until all bubbles cease from forming on its surface. The surplus paraffin may be scraped off when the coil is cold, or wiped off whilst warm, and the coil remounted on its base.

Loss of Insulation from Internal Sparking.—This is a most serious injury, which can only be effectually repaired by unwinding the wire and making up the coil afresh. A temporary repair of this injury may be effected by immersing the coil in melted paraffin, as for repair of insulation through damp. The causes of this injury are, generally, defective insulation of the secondary wire, too much wire in one division of the coil, defective partitions of the divisions, defective joints between the parting discs and the primary tube, defective primary bobbin and tube, defective insulating tube (too thin or faulty at the ends) separating the secondary from the primary, and employment of a battery current of excessive strength. To these may be added the injuries resulting from lateral sparking across the turns or over the dividing partitions of a coil, and accidental contact with the discharging tongs or ends of the secondary wire. When such injuries as these occur, the coil maker will experience the benefit of insulating the wire with paraffin, as the secondary wire must be all

unwound. If insulated with compositions and varnish, it will be almost impossible to unwind the wire, and certainly impossible to get it off without irretrievably ruining the insulating covering, thus rendering the wire useless. If the coil has been insulated with paraffin, detach it from the base and all its connections, remove the outer covering and padding, if any, remove the secondary binding screws by unscrewing them, and get out the ends of the secondary wires. Mount the coil between a pair of standards between centres, or on a spindle as an ordinary bobbin of wire, and well warm it all over before attempting to unwind the wire. The wire may be unwound by running it from the coil on a bobbin mounted in a lathe or on a coil winder, or on a spinning wheel. Run the wire through a piece of stout canvas, held in the left hand, and turn slowly so as to carefully examine the insulation as the wire is being unwound. If the defect appears in the covering of the wire, the damaged spots may be repaired with a thread of soft silk soaked in paraffin wound around the defective covering. The whole wire should be run through melted paraffin before the coil is re-wound. When the secondary has been removed, examine the covering on the primary tube and the joints of the discs for pinholes or black specks denoting spark perforations. Remove the old insulating material and substitute new, taking the same precautions as for a new coil in having the paper quite free from flaws and pinholes and well soaked with paraffin. If the fault lies in the joints of the ebonite partitions, fill them in with soft cotton soaked in paraffin.

If the tube is too thin, thicken it with several folds of paraffined paper. If too thin at the ends, increase the folds of paper at these parts. When all repairs have been done to the tube and primary, make up the coil anew, or wind it with new wire. It will be advisable, to make sure of the insulation, to soak the coil in melted paraffin before fixing it again.

Loose Connections.—Sometimes a coil will fail to act because the connections have shaken loose. This fault may be discovered by opening the false bottom of the base or case containing the condenser, and examining the screws under the contact spring and pillar and their connections with the condenser. These may need tightening and soldering. Care must be taken in examining and re-connecting the wires to restore the connections as at first. I have known amateurs to be much puzzled with these parts, and to re-connect the wire so as to short-circuit the primary, cutting the condenser and rheotome, or one of them, entirely out of circuit.

Piercing of the Condenser.—This not unfrequently happens from bad insulation, as well as from an excess of current. Sparks from the coil pierce the defective paraffined paper and short-circuit the sheets of tinfoil. If a coil gives a diminished spark at the secondary terminals and an increased spark at the contact breaker, we may suspect injury to the condenser. A spare condenser should be at hand. The suspected condenser can then be taken out and replaced by the new condenser in a few minutes, when if the coil goes right we

may examine the old one for defects, unsoldering the connections and pulling the old condenser to pieces, sheet by sheet, holding up each sheet to a strong light and thus search for the holes in them.

Burning of Contact Points.—When an excessively strong current is sent through the primary, or the condenser becomes damaged, or the platinum contact tips and studs are too small, they are liable to be burnt by the thick sparks passing between them. This burning of the contacts may result in a partial fusion of the parts and a consequent sticking together. If the contacts are not badly burnt, but only worn to a thin point, they may be repaired by filing the surfaces smooth and true with a fine smooth file, so as to get two true broad surfaces in contact, and so lessen their resistance. But, if the tips and studs are much burnt, they must be removed by unsoldering or drilling, and new ones substituted.

Broken Wires.—The very fine wires of the secondary coil are liable to be broken whilst repairing other parts of the instrument. If the finish end of a section gets broken, the injury may be easily repaired by taking one turn of wire off the section and using this to make a new connection. A better method, however, is to solder the short end to a thicker wire and wind this once or twice around the coil before leading it off to the terminal screw. If the commencing end is broken, it must be similarly repaired by soldering a piece of thicker wire to it and winding this once or twice around the coil to lessen the strain on the finer wire. If the

end is broken beyond reach, the coil must be unwound until the broken end is found, then repaired by soldering it to a piece of thicker wire.

These are the principal injuries likely to be sustained by coils. Advice respecting the repair of injuries to coils can generally be obtained by sending a letter to the editor of such weekly journals as *Work* and the *English Mechanic.*

CHAPTER VIII.

USEFUL NOTES ON COILS.

§ 76. USES OF COILS.—Induction coils have been and are employed for a number of useful purposes, apart from those of furnishing instruction to the rising generation of amateur electricians and young students of science. Their use by the medical profession has been noticed in previous sections of this book. A full description of the use of the medical coil would be out of place here. A list of books on this subject is published in Mr. K. Schall's Price List of Electro-Medical Apparatus. The spark induction coil has been and is used for lighting gas jets in the halls of public institutions. Wires led from the secondary terminals of a coil, convey the high tension current to any number of groups of gas jets, and the sparks pass from one platinum point to another across the issuing jet of gas, thus lighting it and others in the same group. A suitable switch near the coil directs the current to each group as required. These gas lighters are supplied by all manufacturing electricians and dealers in electrical sundries. This coil has also been employed in exploding

fuses, in blasting operations, and for similar purposes. It is also a powerful agent in the hands of the experimental chemist for separating the component parts of complex substances by decomposition. Leyden jars may be charged by the current from a coil in the following manner:—Connect the secondary terminals of the coil to a pair of dischargers (described and illustrated in § 25, p. 75) and bring the points to a discharging distance from each other. Next, disconnect one of the pair from one of the secondary terminals and connect this terminal to the outer coating of the Leyden jar, then connect the inner coating of the jar to the discharger previously disconnected from the secondary terminal. The path for the current will now be through the jar or battery of jars by way of the dischargers, that is to say, the battery of Leyden jars has been taken in as a loop of the discharging circuit. If the points of the discharger are allowed to touch each other, the jars will be alternately charged and discharged, and, as a consequence, no progress can be made in charging them. But by arranging the points at such a distance as to allow a spark to pass between them, only the alternate impulses of the current (those which pass on opening the primary circuit and have a higher potential than the others) pass into the jars, and it is these impulses which charge the battery.

Small induction coils are employed in telephone systems, together with microphones to intensify the sounds given out by these instruments. A long illustrated description of this use of the induction coil is

given by Mr. F. C. Allsop in the *English Mechanic* for Sept. 18th and Oct. 9th, 1891. It is also illustrated and described in the "Practical Telephone Handbook" published by Messrs. Whittaker & Co., price 3s. 6d.

§ 77. THE TRANSFORMER.—The crowning use of Oersted's discovery is, however, its adaptation to the purposes of electric light manufacturers in the instrument known under the name of a "Transformer." By the use of this instrument it has been found possible to transmit currents of a startlingly high potential to a great distance from the generator, and to transform them into currents of a low potential suitable to the purposes of electric lighting. This has been done by Mr. Ferranti, who has had a large generating station erected at Deptford, where a current at a pressure of 10,000 volts is generated, and conveyed through a specially-constructed main to receiving stations in the West-end of London, in which the high tension current is transformed to a lower tension suitable for lighting incandescent electric lamps in the surrounding houses. The transformer is simply a very large induction coil reversed. The high tension current of small volume is made to pass through the thin wire of many turns, and in doing so induces a large volume of current at a lower potential in the coil of thicker wire with fewer turns. At the present time only the alternating currents from the alternating class of dynamos can be thus transformed. Direct and continuous currents would require an automatic rheotome, or make and break arrangement, to the transformer, since inductive effects in the form of

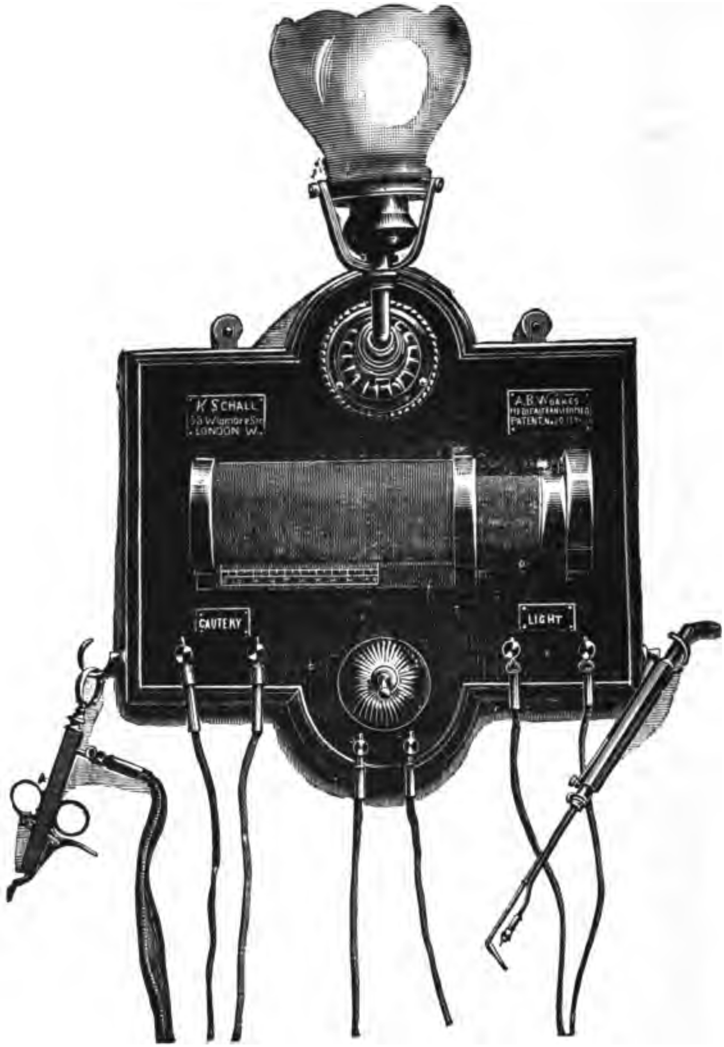


FIG. 101.
Wooke's Patent Medical Electric Current Transformer.

a useful current can only be obtained when the primary current is interrupted. The heating effects of such an interruption in a current of a high potential would entirely destroy platinum contact pieces, and volatilise mercury, so that the ordinary "make and break" arrangements for induction coils are not admissible in the construction of transformers. The manufacture and repair of these instruments may be regarded as being outside the province of the amateur coil maker, and consequently beyond the scope of this work.

An interesting adaptation of the transformer induction coil to medical and surgical purposes has been made by Mr. K. Schall, and is illustrated in Fig. 101. A sledge medical coil is so arranged as to send the battery current by means of suitable switches through the long coil of thin wire or the short coil of thick wire. The induced current can by this means be altered at will to give the usual shocking effects, to heat a cautery, or to light an electric lamp.

§ 78. TABLE OF COPPER WIRE PROPERTIES.—The following table of copper wire properties, compiled from several sources, will be found useful to coil makers. As copper wires vary in purity and consequent conductivity, and the insulating coating on them varies in thickness, the figures here given can only be taken as approximate. The resistances were calculated at 65° Fah. The prices are those given in the price list of Messrs. King, Mendham & Co., Bristol, and are only inserted as a guide to amateurs in calculating the approximate cost of wire for coils.

TABLE OF COPPER WIRE PROPERTIES.

No.	Decimals of an Inch			B.W.G. Yards to the lb.			Turns to 1 in.		R. per lb.	Length in ft.	Price per lb.		Safe Current in Ampères.
	B.W.G.	B.T.G.	B.S.G.	U.C.	S.C.	C.C.	S.C.	C.C.	Ohms.	Per ohm.	S.C.	C.C.	
8	·165	·16	·12849	4·05	4	4	5	5	·00475	2564·1	2/7	1/9	40
10	·134	·128	·10189	6·14	6	5·8	7	6	·0109	1666·6	2/8	1/9	28
12	·109	·104	·08081	9·28	9	8·8	9	8	·0249	1098·9	2/9	1/10	18
14	·083	·080	·06408	16	15·7	15.5	11	10	·0741	666·66	3/	1/11	10
16	·065	·064	·05082	26	25·5	24	15	14	·1971	400·00	3/2	2/	6
18	·049	·048	·0403	47·9	47	45	20	17	·6629	212·76	3/5	2/1	3
20	·035	·036	·0358	85	83	80	26	23	2·095	120·48	3/7	2/2	2
22	·028	·028	·0253	131	129	120	29	27	4·976	77·51	4/	2/6	1·5
24	·022	·022	·0201	176·4	173	162	34	30	9·009	57·80	4/4	2/9	1·0
26	·018	·018	·0159	305	300	280	40	37	27·01	33·33	4/10	2/11	·05
28	·014	·0148	·0126	430	411	395	55	39	53·72	23·58	5/5	3/4	—
30	·012	·0124	·0100	562	540	516	57	41	91·61	18·08	6/3	3/10	—
32	·010	·0108	·0079	765	734	690	64	47	169·7	13·28	6/9	4/6	—
34	·0096	·0092	·0063	1102	1040	964	73	55	351·9	9·23	7/8	4/11	—
35	·0087	·0084	·0056	1457	1366	1214	79	58	614·3	6·98	8/6	5/10	—
36	·0079	·0076	·0050	1767	1650	1472	84	62	903·5	5·75	9/7	6/9	—
38	·0061	—	—	2532	2280	—	110	—	1855	4·01	12/2	8/6	—
	·0058	—	—	3278	2850	—	—	—	3110	3·09	16/7	13/	—
	·005	—	—	4411	3780	—	—	—	5631	2·30	21/7	—	—
40	·004	—	—	6894	5740	—	—	—	13753	1·47	24/7	—	—
—	·003	—	—	12256	9800	—	—	—	43471	0·83	38/	—	—
—	·002	—	—	27546	20700	—	—	—	22022	0·36	63/	—	—
—	·001	—	—	110188	—	—	—	—	3416825	·0967447	—	—	—

References: B.W.G. = Birmingham Wire Gauge.
B.T.G. = Board of Trade Wire Gauge.
B.S.G. = Brown & Sharp's Wire Gauge.

U.C. = Uncovered.
S.C. = Silk-covered.
C.C. = Cotton-covered.

§ 79. INSULATING MATERIALS.—Of the several insulating materials employed in electrical industries, only a few are in use by coil makers. Paraffin is the insulator most in favour, since it can be made to permeate wood, cloth, canvas, cotton, silk, and paper, and increase the insulating properties of these materials. Section 11 (p. 38) has been devoted to a notice of this insulator. For an insulating wire-covering, silk and cotton are the only materials employed, silk being preferred to cotton because its fibres lie closer together when wound around wire, and thus form a closer covering in a smaller space than that obtained from cotton. It is also an inferior conductor to cotton. No better insulator for wire, from the coil-maker's point of view, can be had than silk well soaked in paraffin. Wool is a good insulator, superior to cotton, but its fibres are loose, and the consequent covering too bulky to be of any practical service. India-rubber as a covering for wire is untrustworthy, since it is liable to deterioration by age, the material being slowly oxidised and rendered friable by atmospheric changes. It can also be rendered soft and useless by contact with grease, oil, and other animal substance. Gutta-percha is liable to a similar deterioration, the resinous result being more friable than that of india-rubber. When india-rubber is subjected to the process of vulcanisation—*i.e.*, made into a paste whilst being heated with some sulphur compound, a stronger material, known as vulcanised rubber, is produced. If the process is carried to excess by heating the mixture to a higher temperature, the rubber loses its softness and elasticity

and becomes a hard, black, brittle substance known as ebonite or vulcanite. Both names are synonymous for the same material. Gutta-percha can be similarly treated and made into ebonite, but this differs from the rubber product in being more brittle, and not so much affected by high temperatures. Ebonite made from rubber may be made pliable and semi-plastic at a temperature of about 100° C., or the boiling point of water. In this state it may be moulded to any form, which will be retained when the material has cooled. Ebonite or vulcanite tubes, discs, and rings make the best bobbins for coils. This material may also be used for pillars and handles of dischargers, and for the base of the coil itself. It can be cut with a saw, drilled, bored, and filed like ebony or similar hard substance, and will take a coarse screw thread fairly well. The screws for ebonite should, however, have coarse threads with rounded instead of sharp corners, as these cut away the material and loosen its hold on the screw. Ebonite oxidises more slowly than uncured rubber or gutta-percha, but inferior qualities are liable to a similar deterioration from the same causes as the uncured material. In this condition its insulating properties are impaired, but may be repaired by warming the material before a fire and painting it with a shellac spirit varnish. Boxwood is a good insulator, because of its density and the natural oil which it contains, but it is brittle and liable to split under variations of temperature. Ivory is an excellent insulating material, but its cost is high. Hardwood baked to drive out all moisture and then soaked in melted

paraffin until all bubbles cease from forming on the surface of the wood, is also an excellent and cheap insulator. If the wood has been previously planed and polished, the polish may be restored after the wood has been baked and paraffined.

Papier-maché well soaked in paraffin is also a good insulating material. Glass and porcelain have also been used, and also polished slate and marble. These are all good insulators, but are substances not easily worked. Shellac and resin, asphalte and pitch, and similar materials, although bad conductors of electricity, are much too brittle for use in coil-making.

§ 80. LIST OF CONDUCTORS AND NON-CONDUCTORS OF ELECTRICITY.—As these terms are misleading, there being no such thing as a non-conductor of electricity, the substances mentioned in the following list are classified under the names of "good conductors" and "bad conductors." Their positions are relative on the list, but figures are useless for comparison, since the conductivity and resistance of each must be governed by the bulk, sectional area, thickness, length, &c., of the material employed as a conductor or insulator. Taking annealed pure silver as the unit of comparison in the following list, the relative value of the other conductors may be approximately determined as being so many times that of this metal. Where no figures are given, the relative values have not been determined by any authority, or have not been accurately measured. This list has been copied by permission from Mr. Bottone's book on electric bells, published by Messrs. Whittaker &

Co. A few slight alterations have been made by permission of the author.

TABLE OF CONDUCTORS AND INSULATORS.

Quality.	Name of Substance.	Relative Resistance and Conductivity.	
Good Conductors.	Silver, pure annealed	1·	Resistance higher than that of pure silver. Conductivity lower than that of pure silver.
	Copper, pure annealed	1·063	
	Silver, hard drawn	1·086	
	Copper, hard drawn	1·086	
	Gold, annealed	1·369	
	Gold, hard drawn	1·393	
	Aluminium, annealed	1·935	
	Zinc, pressed	3·741	
	Brass (resistance variable with quality)	About 5·000	
	Platinum, annealed	6·022	
	Iron	6·450	
	Steel, soft	6·500	
	Gold and silver alloy, 2 to 1	7·228	
	Nickel, annealed	8·285	
	Tin, pressed	8·784	
	Lead, pressed	13·050	
	German silver (a variable alloy)	13·920 (or 13 to 14).	
	Platinum, silver alloy, 1 to 2	16·210	
	Steel, hard	25·000	
	Antimony, pressed	23·600	
	Mercury	62·730	
	Bismuth	87·230	
	Graphite (gas carbon)	145·c00	

Metals become worse conductors when heated.
Carbon becomes a better conductor when heated.

Quality.	Name of Substance.	Relative Resistance.
Imperfect Conductors.	Nitric Acid	976000.
	Hydrochloric Acid.	*
	Sulphuric Acid.	1032020.
	Solutions of Metallic Salts.	Variable.
	Metallic Sulphides.	*
	Distilled Water.	6754208.
Inferior Conductors.	Metallic Salts.	* The resistances of these have not been accurately measured.
	Linen, Cotton, Hemp.	*
	Paper and Cellulose.	*
	Alcohol and Ether.	*
	Dry Wood.	*
	Dry Ice.	*
	Metallic Oxides.	*
	The conductivity of Acids and Solutions of Metallic Salts increases when these are heated. The resistance of salts increases as they are dried. The conductivity also varies with their purity.	

Quality.	Name of Substance.	Relative Resistance.
Bad Conductors or Insulators.	Caoutchouc or India rubber.	1,000,000,000,000.
	Gutta-percha.	" "
	Ebonite.	1,300,000,000,000.
	Ice at 25° C.	* Relative resistances of these have not been accurately measured.
	Fats and Oils.	*
	Dry Air, Gases, and Vapours.	*
	Wool.	*
	Diamond.	*
	Silk.	*
	Glass.	*
	Wax, Sulphur, Resin.	*
	Amber, Shellac.	*
	Paraffin.	1,500,000,000,000
	Dry Air is a very bad conductor, but this is hardly obtainable, since air so soon becomes humid under atmospheric changes.	

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C.

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